RESEARCH PAPER

Neighborhood Walkability Index and Its Association With Indices of Childhood Obesity in Bengaluru, Karnataka

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Background: The prevalence of childhood obesity is increasing in low and middle-income countries like India. Built environment features such as walkability can influence weight-related outcomes but data from developing countries are scanty.

Objective: To develop a population level walkability index in urban Bengaluru and examine its association with indices of childhood obesity in school children.

Study Design: Nested cross-sectional study based on a an existing cohort (PEACH).

Participants: Normal healthy children aged 6 to 15 years, from urban schools in Bengaluru. The children were stratified into different land use classification such as residential, commercial and open space based on residential address.

Methods: Anthropometric data, and body composition data, measured using air displacement plethysmography, were collected.

Outcomes: Walkability index was derived using residential density, street connectivity and land-use mix environment variables.

Results: The mean (SD) of age, body mass index (BMI), BMI *z*-score and percentage body fat (% Body fat) of 292 (50% boys) children were 10.8 (2.9) year, 17.4 (3.3) kg/m^2, -0.27 (1.35) and 20.9% (8.8), respectively. The mean (SD) walkability index was 16.5, which was negatively associated with BMI (slope -0.25 and -0.08) and percentage body fat (slope -0.47 and -0.21) for age 5 and 10 years, respectively in children, but the effects decreased with increasing age.

Conclusions: The findings of this pilot study suggest that the neighborhood walkability may be associated with obesity indices in younger children. Further longitudinal studies are needed to understand how built environment affects health and body composition of children in India and other low-middle income countries.

Keywords: *Air displacement plethysmography, Body mass index, Built environment, Physical activity.*

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The increasing prevalence of childhood obesity is a major global public health challenge, steadily affecting the urban population in India, with combined prevalence of overweight and obesity of 5% in children aged 10-19 years [1]. In urban Bengaluru, 13% of school going children were overweight, while 5% were obese [2]. Multiple lifestyle factors, and genetic, behavioral and environmental conditions contribute to the etiology of obesity, also seen in Indian children [3]. The barriers to physical activity in children include lack of support/encouragement from parents, parental concerns with regard to safety, unsafe neighborhood, increased traffic, risk of accidents, inadequate built environment, and lack of recreational facilities [4]. Built environment can influence weight-related outcomes through physical activity, outdoor play, active transportation, dietary habits and sedentary behavior [5].

Neighborhood walkability, the capability to support walking for multiple purposes such as availing transport, shopping, recreation for children, and commuting for school has shown to promote physical activity and prevent obesity [6]. Increased walkability characteristics have been associated with lower body mass index (BMI) *z*-score in children [7] and in adults [8]. Walkability index, defined as the extent to which the built environment is walking friendly, can be derived by adopting spatial data obtained from geographical information system (GIS); which has become popular to generate measures of specific attributes of the built environment, with its relative convenience, smaller measurement error, higher reliability, and ease of translating to into health and planning policy [9-11].

The need for optimal urban planning and transport policies to create and preserve built environments, with supportive infrastructure for active commuting such as walking and cycling, has been highlighted by the World Health Organization's Global Action Plan for the Prevention and Control of NCDs, 2013-2020 [12]. India is faced with multiple problems such as lack of supportive infrastructure, traffic congestion, overcrowded streets, air pollution, and in adequate policies/investments to promote active commuting. There are limited Indian studies on neighbor-hood walkability and body weight [13].

Bengaluru is currently placed third among the top 10 fastest growing cities in the world [14]. The effect of urbanization on the prevalence of overweight/obesity among children is important. The primary aim of this exploratory study was to develop population level walkability index for selected localities in Bengaluru city. The secondary objective was to associate the walkability index with indices of childhood obesity such as BMI, body fat, and waist to height ratio (WHtR) in a subset of school children.

METHODS

The Pediatric Epidemiology and Child Health (PEACH) cohort was established by the Division of Nutrition, St. John's Research Institute, Bengaluru in 2011 [15], and the children for the present study were recruited from this cohort from the year 2011 to 2016 [2]. The study was approved by the institutional ethical committee. Normal healthy children aged 6 to 15 years were enrolled into the study, while children with any chronic illness as reported by the parents during the consenting process were excluded. The schools were selected by using convenience sampling procedure for operational feasibility.

The children of the above cohort were stratified into 12 land use classification typologies by combination of different degrees of land use of three basic patterns such as residential, commercial and open space, based on children's residential address.

The anthropometric measurements of body weight, height and waist circumference were performed according to standard techniques [16]. Children were weighed in light clothing using a calibrated digital scale (Salter), to the nearest 0.1 kg. The height was measured to the nearest 0.1 cm using mobile stadiometer (Seca 213). Waist circumference (WC) was measured with a non-stretchable tape by trained nutritionists (exerting the same standard pressure on the tape) at the midpoint of the lowest rib cage and the iliac crest, to the nearest 0.1 cm, in a standing position during end-tidal expiration. The body fat of the children was measured using the BOD POD (Cosmed), with software version 5.2.0, which works on the principle of air-displacement plethysmography (ADP) [17]. The BOD POD was placed inside a van and parked at a location close to the measurement room in the school. The internal CV of body fat by this method was 2.3% [2]. All the other measurements were performed at the schools in a room allotted for the study.

Two frequently used GIS based walkability indexes are the South Australian Physical Activity in Localities and Community Environments (PLACE) study [10] and North American Neighborhood Quality of Life Study (NQLS) [9] walkability indexes. These walkability indexes are constructed by four built environment variables- residential density; street connectivity; land-use mix; and net retail area (a measure of pedestrian friendliness). However, retail area (which is the measure that calculates the retail floor area in relation to the total amount of land area for retail use) information of Bengaluru city was not available electronically in public domain. Therefore, we derived GIS based walkability index in the present study using the other three components (**Web Fig. 1**).

The Global positioning system (GPS) coordinates of residential addresses of 300 students were obtained by Google earth or Open street map from the street level addresses. Further, these GPS coordinates were plotted on open street map to check the accuracy manually by street addresses of the residences and corrected accordingly in case of discrepancy. A buffer of 1 km radius was drawn over each of the residential coordinates within ArcGIS platform [18].

Dwelling density, street connectivity and land-use mix were then derived for each of the buffer from ArcGIS tools. The number of residential units were counted within each buffer from the detailed map of Bengaluru city obtained from local municipality, over total residential area within the buffer. The dwelling density was derived by dividing number of residential units by total residential area within each buffer.

The street connectivity was measured by street intersection density. With the help of Bengaluru map, the number of street intersections were counted within each of the buffer. Further, dividing the same by area of each of the buffer provided intersection density as a measure of connectivity.

Four different land use classification that well defined the variation of the land use such as residential, commercial, park and open space area and public and semi-public area were measured. The sum of land area by the buffers was used to create an entropy score for each buffer, using the entropy equation [10]. The entropy equation results in a score of 0-1; 0 representing homogeneity and 1 representing heterogeneity.

In order to create a standard measure, all the above measures were converted into 10-point scale, with scores from 0 to 10 [10]. The walkability index was calculated by summing up the scores of dwelling density, connectivity and land-use mix; the calculated index would be between 0 and 30, with '0' being the worst and '30' being the best walkability.

Sociodemographic details of selected school going children such as age, sex, BMI, income of parent, parental BMI along with body composition of the children were extracted from original cohort data base.

Statistical analysis: Data were analyzed using statistical software R version 4.1.0 (R core team, 2021). Distribution of health and demographics along with walkability index were summarized by descriptive statistics. Univariate linear regression technique was applied to explore univariate association between BMI, body fat /obesity indicators and sociodemographic parameter. Unadjusted associations between obesity indices and walkability were also examined prior to the estimation of adjusted effects of walkability on obesity indicators. Finally, a multivariate linear mixed model with interaction was used to estimate the effects of walkability on obesity indices adjusted for relevant confounders, effect modifiers and cluster effects of school.

RESULTS

The total cohort size was 9060 children (5172 boys and 3888 girls). A stratified random sample of 300 children was selected from the cohort as per the land use classification (**Fig. 1**).

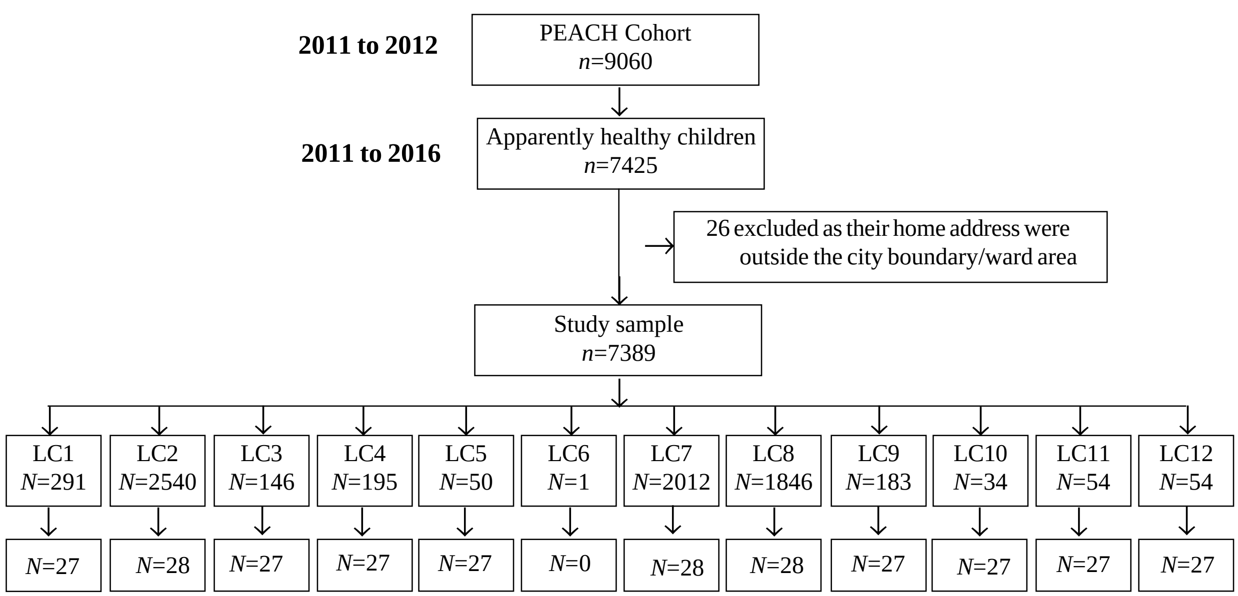
However, due to non-availability of body composition data of some of the selected children, the effective sample size was 292 (146 boys). Fifteen (5%) children were obese while 44 (15%) were overweight based on BMI *z*-scores. Only 260 households had complete family income data with mean family income INR 26000 to 30000 (USD 345 to 398) per month. The descriptive statistics are reported in **Table I**. **Web Fig. 3** depicts distribution of walkability across households of the study participants.

Table I Baseline Characteristics of the Study Population (*N*=292)

Variable	*Value*
Age (y)	10.84 (2.89)
Body mass index (BMI) (kg/m^2)	17.39 (3.26)
BMI *z*-score	-0.27 (1.35)
Waist-height ratio	0.44 (0.06)
%Body fat	20.97 (8.78)
Body fat mass (kg)	7.89 (5.23)
Paternal BMI (kg/m^2), *n*=243	25.17 (3.62)
Maternal BMI (kg/m^2), *n*=250	24.97 (4.76)
Walkability index	16.54 (5.87)

Values in mean (SD).

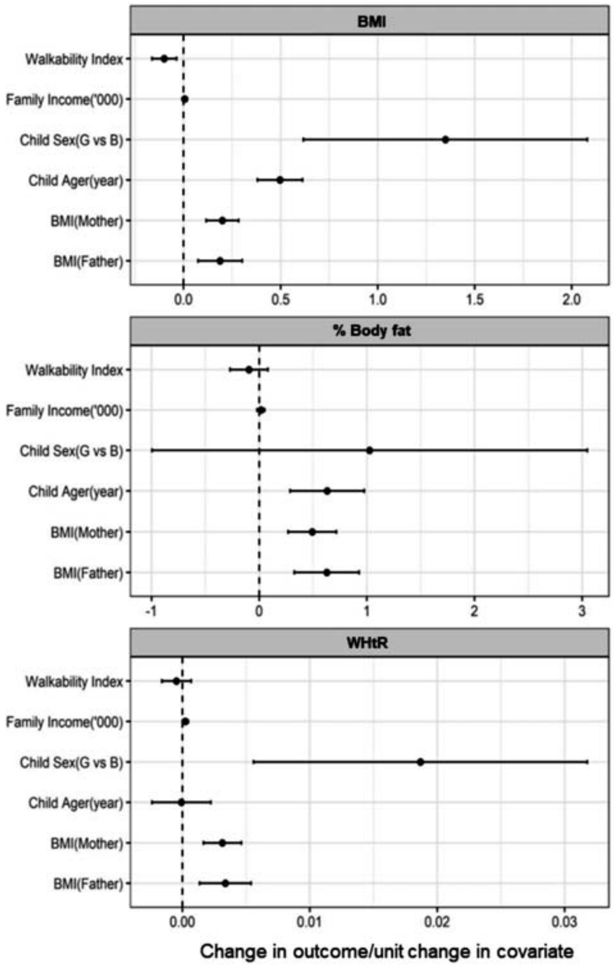
The univariate analysis exhibited significant association between BMI and walkability index, age, sex of the children and parental BMI. The walkability index showed negative associations with percentage body fat and waist height ratio (WHtR) but were not statistically significant (**Fig. 2**). In the present analysis, sex was considered as a confounder in the association of walkability with BMI and percentage body fat. When the association of sex with walkability index was analysed in the regression model by



A stratified random sample of 300 children were selected from the cohort. Out of 12, LCs, LC6 was excluded due to poor representation. Children were equally stratified into 11 land use classification (27 in each. 3 additional children were selected from the 3 biggest strata.

LC=Land use classification

Fig. 1 Selection of study participants.



Vertical dotted lines indicate the null hypothesis values. The error bars that do not intersect dotted lines were considered statistically significant.

Fig. 2 Univariate analysis between *a*) body mass index (BMI), *b*) % body fat and *c*) Weight-height ratio (WHtR) and walkability index, age and sex of the children, parental BMI (the error bar plots compare the unadjusted effects of different covariates and walkability on obesity indicators).

using sex as an interaction term, we observed nonsignificant interaction coefficient, suggesting that there was no effect modification by sex (**Fig. 2**).

The multivariate linear mixed effects with age interaction model that adjusted for sex, family income, parental BMI and cluster effects of schools showed a significant reduction in BMI with increase in walkability index, but the impact decreased with age (**Table II**). The slope of BMI as per age of a child was -0.415+0.033×age in years. Similarly, the slope of percentage body fat with respect to age was -0.723+0.051× age (years). The WHtR did not show any significant associations in the multivariate analysis (**Web Fig. 2)**.

DISCUSSION

The present study developed population level walkability index for selected localities in Bengaluru and examined its association with indices of obesity in school going children. Walkability index is a quantifiable index to study health-promoting effects of the built environment that was negatively associated with the BMI and percentage body fat of children.

Studies from other countries have shown mixed results in the associations between walkability and childhood obesity [19-21], which could be due to difference in analytical methods, measurement of study variables like BMI, self-reporting of weight and height, and cross-sectional nature of the studies. However, the concept of an anti-obesogenic environment, including improved walkability, is plausible. Additionally, the results from Western countries cannot be inferred for a LMIC like India, where the built environment has distinct patterns of urbanization, density, and land use. With the rapid increase in the prevalence of childhood overweight/obesity and adult non-communicable disease, it is important to understand the associations and develop country-specific solutions for India.

Walking is a significant mode of transport in India, but the difficulties faced by the pedestrians are lack of sidewalks, disappearing zebra crossings, traffic, and ongoing road constructions/repair work [22]. Only 38% of young adolescents and 17% of children in India were found to achieve the recommended 60-minutes/day of moderate-to-vigorous intensity physical activity (MVPA) duration [3]. The differences in physical activity between gender, socio-economic status and type of school (public vs private) have also been observed in Indian children [23,24].

The present study observed the effects of walkability index on BMI and percentage body fat to decrease with age. While the exact reason for this is not clear,

Table II Adjusted Estimates of Effect of Walkability on Obesity Indicators

Outcome	*Exposure*	*Change in outcome/ unit change in walkability*
BMI	WI	-0.41460 (-0.52501, -0.30418)
	WI × Age	0.03304 (0.02547, 0.04060)
WHtR	WI	-0.00198 (-0.00422, 0.00027)
	WI ×Age	0.00011 (-0.00005, 0.00026)
% Body fat	WI	-0.72318 (-1.04723, -0.39913)
	WI × Age	0.05108 (0.02851, 0.07366)

Values are in slope (95 % CI). BMI-body mass index; WHR-waist-height ratio; WI-walkability index.

WHAT IS ALREADY KNOWN?

- Built environment features such as walkability can influence weight-related outcomes.

WHAT THIS STUDY ADDS?

- The present study developed population level walkability index for selected localities in Bengaluru
- Walkability index was negatively associated with the body mass index and percentage body fat of children.

psychosocial factors like social support from peers affected the associations between the built environment and active commute from schools (ACS) among adolescents [21]; adolescents chose the mode of transport to school based on ACS [21]. Younger children may not have the freedom for independent decision for walking plus ACS. Additional postulated reasons could be time spent in active games, academic pressure, increased mobile phone, screen and sedentary time duration, and dietary habits, which were not evaluated in this analysis.

The limitations of the study included small sample size, cross-sectional study design and lack of objective assessment of physical activity. The lack of information on the retail area of Bengaluru city in the public domain limited the inclusion of this parameter while calculating the walkability index, which might have affected its accuracy. We anticipate that the true walkability index as defined previously [9,10], would have been adequately captured by the modified index of this study, as it considered three out of four domains. The lack of data on clear classification of land use patterns was another limitation. Data on facilities in the neighborhood like recreational facilities or food outlets were not captured. Future studies in India and other LMICs need to be planned, keeping in mind the limita-tions of unavailability of relevant data in LMICs. Large scale studies with multilevel approach examining the neighborhood effect on individual-level health outcomes are needed.

In conclusion, this pilot study suggests that neighborhood walkability is associated with the obesity indices in younger children, and can be a catalyst for future longitudinal studies examining the associations of walkability with weight-related behaviors and outcomes. Future studies need to look into the individual components of walkability and built environment to understand how environment and health interact in an LMIC country like India.

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