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Citation (APA)
Tyagi, M., Adlakha, D., & Bisht, L. S. (2026). Supporting adolescent physical activity through walkable neighbourhoods: Evidence from Indian cities during COVID-19. *Journal of Transport and Health*, *51*, Article 102417. https://doi.org/10.1016/j.jth.2026.102417

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Journal of Transport & Health 51 (2026) 102417

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Supporting adolescent physical activity through walkable neighbourhoods: Evidence from Indian cities during COVID-19

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ARTICLE INFO

Keywords:
Adolescents
Physical activity
Neighbourhood walkability
COVID-19
India

ABSTRACT

Introduction: Physical inactivity among adolescents remains a critical global health concern that was further exacerbated by the COVID-19 pandemic. In low- and middle-income countries such as India, the potential influence of neighbourhood environments on adolescents' physical activity (PA) and overall well-being has long been overlooked in empirical research and policy development. This study investigates the relationship between perceived neighbourhood walkability and adolescents' out-of-school PA in India, both pre-pandemic and during the pandemic.

Methods: A cross-sectional survey design was employed, collecting data from 500 adolescent-parent dyads in 2021 across four major Indian cities. Adolescents self-reported their out-of-school PA, while perceived neighbourhood walkability variables were obtained from parents by employing the Neighbourhood Environment Walkability Scale for India (NEWS-India). Binary logistic regression was employed to analyse the association of PA with perceived neighbourhood walkability.

Results: Findings revealed that before the pandemic, higher 'household vehicular ownership' and perceived 'traffic safety' were found to increase the likelihood of adolescents being physically active, with latter resulting in 1.7-fold increase in PA. While during the pandemic, ensuring safe and continuous operation of local recreational facilities were recognised as extremely vital for supporting adolescent PA beyond school.

Conclusion: These results highlight the importance of neighbourhood-level mobility planning in creating safe and accessible environments for adolescents' health and well-being both in everyday life and during future public health crises.

1. Background

Global trends indicate a concerning decline in physical activity (PA) among adolescents, with four out of five individuals aged 11–18 failing to meet the World Health Organization's (WHO) recommended daily PA guidelines (Aubert et al., 2018; Rhodes et al., 2017). This issue was further exacerbated by the COVID-19 pandemic, which significantly disrupted adolescents' daily routines, mobility patterns, and access to PA opportunities (Neville et al., 2022; Zenic et al., 2020b).

India, home to the world's largest adolescent population, imposed the longest pandemic related restrictions, especially for school-

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https://doi.org/10.1016/j.jth.2026.102417
Received 29 August 2025; Received in revised form 18 June 2026; Accepted 11 August 2026
Available online 17 August 2026
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going adolescents (Raut and Huy, 2022). It not only adversely impacted their PA, but also intensified their sleep disorders, depression, anxiety, increased screen time, loneliness, and sedentary lifestyles (Daniel et al., 2022; Datta and Kundu, 2021; Gupta et al., 2024; Moitra and Madan, 2022). Several researchers have linked these outcomes to prolonged school closures, highlighting the substantial reliance on schools in India to fulfil children's emotional, nutritional and developmental needs, often considered more enriching than home environments (Gupta et al., 2024; Patra and Patro, 2020). This overdependence on schools, evident even before the pandemic, has persistently undervalued the significance of neighbourhood-built environment, particularly in supporting adolescents' PA within the broader policy discussions and empirical research. Evidently, despite recognizing non-communicable diseases as a key focus area within national adolescent health program, India does not have any national or sub-national level-built environment guidelines for promoting adolescent's PA (Barua et al., 2020). A trend reflected during government's pandemic response, which prioritized and focused exclusively on reopening schools (Sharma and Joshi, 2021). Even the limited literature that emerged during COVID-19 on adolescents, predominantly centered around mental health risks, thereby perpetuating the negligence of built-environment's role in shaping adolescent PA (Dandona and Sagar, 2021; Gupta et al., 2024; Jeelani et al., 2022; Mahapatra and Sharma, 2021; Sharma et al., 2022).

Today, there is ample empirical evidence that underscores the significance of adolescent's out-of-school PA over structured school-based PA especially obtained through active mobility (Gidlow et al., 2008; Janeckova et al., 2021; Kinder et al., 2019; Oliver et al., 2015). Both walking and cycling have been found to not only enhance adolescent's everyday PA, but also their spatial cognizance, place attachment, social and mental well-being (Carver et al., 2011; Schoeppe et al., 2013; Stark et al., 2025). International research has consistently demonstrated that perceived neighbourhood walkability plays an important role in shaping adolescents' PA, supporting not only their active travel but also outdoor recreation and independent mobility. Studies from North America, Europe, and Asia have reported positive associations between perceived neighbourhood attributes such as street connectivity, access to destinations, walking and cycling infrastructure, aesthetics, and safety and adolescents' PA levels (Cerin et al., 2019; Rosenberg et al., 2009; Timperio et al., 2025). Among these factors, parental perceptions of traffic and crime safety have been identified as especially influential, as they often determine adolescents' opportunities for independent movement and outdoor activity (Kerr et al., 2006; Tristram et al., 2023). However, findings have not always been consistent across settings, with the relative importance of specific walkability attributes varying according to local socio-cultural norms, urban form, and mobility practices.

The COVID-19 pandemic further highlighted the significance of neighbourhood environments for adolescent PA. With school closures, restrictions on organized sports, and reduced access to recreational facilities, neighbourhoods became the primary settings for PA. Studies conducted during the pandemic found that adolescents living in more walkable neighbourhoods, with better access to parks, open spaces, and recreational opportunities, were more likely to maintain or increase their PA levels than those living in less supportive environments (Gu et al., 2023; Mitra et al., 2023; Mitra et al., 2020;Rossi et al., 2021; Zenic et al., 2020a). Conversely, limited access to outdoor spaces and heightened mobility restrictions were associated with declines in PA and increases in sedentary behaviour (Do et al., 2022; Hunt et al., 2024; Ng et al., 2020). These findings suggest that the influence of neighbourhood walkability may become even more pronounced during periods when access to schools and other structured environments is disrupted.

Yet, arising from the broader historical under-recognition of the built environment's role in adolescent's everyday life, there exists limited research on walkable neighbourhoods and adolescent's PA in Indian context. Recent scholarly attention to walkability in India has primarily encompassed adults, focusing on operationalizing a contextual walkability index, by including adult's perception and satisfaction with pedestrian infrastructure such as sidewalks and crossing facilities (Adlakha et al., 2017; Bhaduri et al., 2019; Bivina et al., 2019; Majumdar et al., 2021; Nag et al., 2020; Rani et al., 2021; Shkera and Patankar, 2025). Predictably, safety from crime and traffic has been recognised among the most significant enablers, sometimes outweighing factors such as comfort and convenience in promoting actual walking behaviours (Bivina et al., 2019; Vendoti et al., 2020). Mondschein (2023) describes this disconnect between neighbourhood walkability and actual pedestrian experiences in Indian cities as “walking dissonance”, a condition in which individual walk frequently despite poor walkability perceptions. Furthermore, emerging studies have begun incorporating variables like ‘pollution’ and ‘thermal comfort’ as factors influencing walkability in India (Kaushik, 2025; Mohite and Surawar, 2024). However, research specifically examining the associations between walkability and PA remains limited. For instance, Hong et al. (2025) explored the influence of perceived neighbourhood satisfaction—encompassing aspects like safety after dark, park availability, and environmental satisfaction—on adult PA in two Indian cities during COVID-19. Conversely, Patel et al. (2024) investigated children's perceptions of air pollution and built environment factors—such as zebra crossings, crime rates, pedestrian signals, and natural attractions—on their moderate to vigorous PA across 28 urban and rural locations during the pandemic. While both studies are noteworthy in providing empirical evidence on the relationship between the built environment and PA during pandemic, neither specifically addresses walkability. Moreover, existing studies from India that do examine the relationship between PA and perceived walkability tend to focus on adults and have reported mixed results. They found positive influences from factors like residential density and land-use mix, and contrasting impacts from crime safety concerns and aesthetics on PA-related active commuting or travel PA (Adlakha et al., 2017, 2018; Adlakha and Parra, 2020; Prithviraj and Sundaram, 2023).

In view of the above discussion and to contribute to the growing body of research on adolescent PA in India, this study investigated the influence of perceived neighbourhood walkability on adolescent's out-of-school PA in India before and during the COVID-19 pandemic. Drawing on cross-sectional data from 500 adolescent-parent dyads across four Indian cities-Chennai, Bengaluru, Hyderabad and Kochi, the study addresses the following research questions: (1) Which socio-demographic factors were associated with adolescents' out-of-school PA before and during the COVID-19 pandemic? and (2) How were perceived neighbourhood walkability characteristics associated with adolescents' out-of-school PA before and during the COVID-19 pandemic?

2. Methods

2.1. Setting

This study draws on the Active and Healthy Environments for Adolescents (AHEAD) pilot project and is the first in India to apply the Neighbourhood Environment Walkability Scale for India (NEWS-India) to assess PA outcomes among adolescents. Using a randomized cross-sectional sampling design, the study recruited 500 adolescent-parent dyads in 2021 from four major Indian cities: Chennai, Bengaluru, Hyderabad, and Kochi. Fig. 1 illustrates their geographical locations and Table 1 presents key demographic characteristics of the sample. These cities were selected for their rapid urbanization rates and dynamic economic growth, each representing a distinct urban typology within the Indian context.

Notably, three of these cities—Chennai, Bengaluru, and Hyderabad—are state capitals, serving as central hubs for administrative, economic, and cultural activities. In contrast, Kochi functions as the economic capital of Kerala, distinguished by its major port

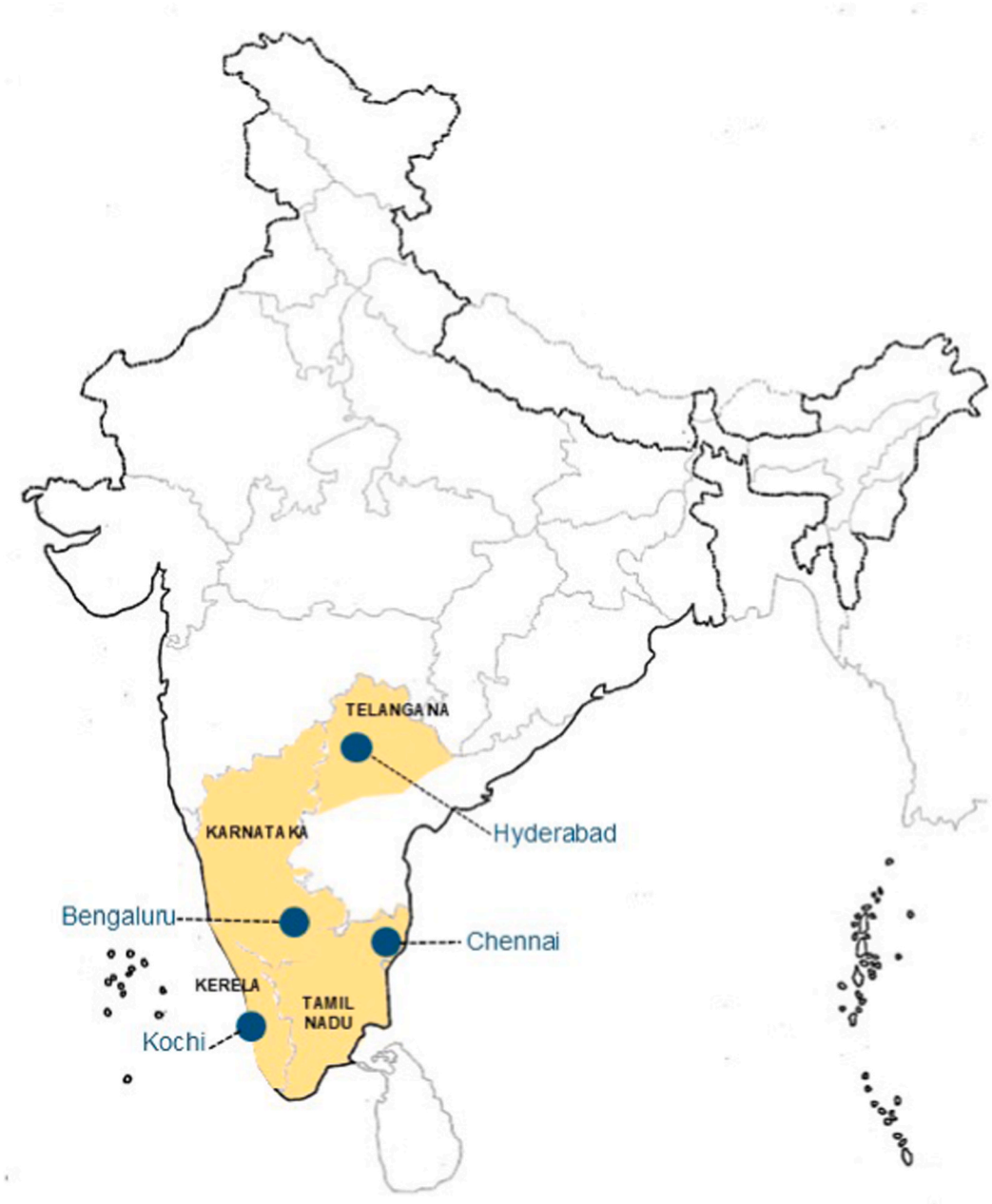


Fig. 1. Map showing the location of Indian cities selected for the study.

Table 1
Demographic characteristics of selected cities in India.

City Demographics	Chennai[a]	Bengaluru[b]	Hyderabad[c]	Kochi[d]
Population in city municipality (in millions)[e]	4.68	8.4	7.7	0.60
Decadal population growth between 2001 and 2011 (in percentage)	27	49.44	32	8.4
Adolescent population between 10 and 19 years old (in percentage)[e]	15.3	15.5	18.2	14.5
Population density (persons per sq. km.)	26,400	11,800	1070	7034
Total city municipality area (sq. km.)	426	712.54	650	95

[a] Comprehensive Mobility Plan for Chennai Metropolitan Area (2019).
[b] Comprehensive Mobility Plan for Bengaluru (2019).
[c] Long Term Strategy for the Transport Sector of HMA-2041 (2013).
[d] Draft Comprehensive Mobility Plan for Greater Kochi Region (2024).
[e] As per the latest Census 2011. The Indian government is in the process to conduct the next census in the country.

activities. Among these cities, Bengaluru exhibits the largest population and geographic area, yet Chennai demonstrates the highest population density, reaching nearly double that of Bengaluru. Kochi, with its smallest population, presents a contrasting urban scale. Hyderabad ranks highest in its proportion of adolescent residents (18.2%), aligning closely with the national average of 21% (Sivagurunathan et al., 2015).

From a transportation perspective, both Chennai and Bengaluru exhibit a walking mode share of approximately 25%, indicating a substantial reliance on non-motorized transport. However, both cities face challenges related to insufficient public transport coverage, subsequently contributing to increased private vehicle ownership—a factor significantly influencing urban congestion and traffic safety issues (BMRCL & DULT, 2019; CMRLCMDA and UMTC, 2019). Meanwhile, Hyderabad and Kochi, though having diverse transport options, confront similar urban growth dynamics and congestion challenges (Chidambaram et al., 2014; CSE, 2011; KMRL, 2024). Traffic safety varies across these cities, with Kochi demonstrating relatively lower traffic injury rates, thus presenting a safer environment comparatively (TomTom, 2025).

2.2. Participant recruitment strategy

The study used a randomized, cross-sectional sampling approach based on residential addresses to recruit adolescents and their parents or caregivers across the four cities. Data collection was conducted via telephone and web-based surveys between June 2021 to October 2021 by a market research firm. Each household was limited to one participating adolescent and one parent or caregiver. In cases where parents had more than one child in the eligible age group, they were asked to respond on behalf of only one child selected for participation. Recruitment continued until 125 eligible participants were surveyed from each city, resulting in a total sample size of 500 participants. The sample size of 500 was determined by the logistical constraints of the 2021 COVID-19 s wave in India, targeting 125 participants per city. Sample size adequacy was verified using the Events-per-Variable (EPV) criterion. For the Pre-COVID and During-COVID models, the EPV ratios were 10.44 (94 events/9 predictors) and 9.44 (85 events/9 predictors), respectively. While a threshold of 10 is common, these ratios fall within the statistically robust range recommended for identifying associations in epidemiological studies without compromising model stability or bias (Vittinghoff and McCulloch, 2007).

The online surveys, conducted with each adolescent-parent dyad, lasted approximately 50–70 min. Responses were recorded using a video and audio communication platform with prior consent from participants and were transcribed verbatim.

Although data collection began after the second wave of COVID-19 in India, schools remained closed in all four cities during this period. Parents or caregivers were contacted using telephone or web-based calls to assess eligibility. The inclusion criteria were as follows: (i) the family must reside in the metropolitan area of one of the selected cities; (ii) the adolescent must be between 11 and 18 years old, and the participating parent or caregiver must be over 18; (iii) participants must be fluent in English or one of the official languages of the study sites (Tamil, Kannada, Telugu or Malayalam); (iv) the parent or caregiver must be willing to provide consent and remain physically present during the adolescent's telephone or web-based survey; (v) the adolescent must provide assent to participate; and (vi) there are no signs of significant health, physical, or emotional problems or language-related limitations that could hinder participation in the survey or engagement in PA.

All study procedures were approved by the Institutional Review Board at one of the second authors' previous university, where the project received funding.

2.3. Measures

2.3.1. Adolescent's physical activity measure

Adolescents self-reported their PA based on the frequency of achieving at least 60 min of moderate-to-vigorous activity (MVPA) per day, both before and during the COVID-19 pandemic. They answered two questions: (1) "Over the past seven days, on how many days were you physically active for at least 60 min per day?'" and (2) 'Before the COVID-19 pandemic, over a typical or usual week, on how many days were you physically active for at least 60 min per day?'. Response options ranged from 0 to 7 days for each question.

Before completing the questionnaire, adolescents were provided with a definition of PA as "any bodily movement that increases heart rate and requires energy expenditure," encompassing a wide range of moderate to vigorous activities such as walking, cycling, running, organized sports, and informal sports (Bull et al., 2020). These activities could occur outside school hours, regardless of

whether school was held online or in-person.

Following WHO guidelines on PA and sedentary behaviour for adolescents (WHO, 2020), which recommend an average of 60 min of MVPA daily, responses were dichotomized into two categories: "active' (6-7 days/week) and "inactive" (0-5 days/week) groups. This categorization reflects the WHO's weekly average method, which acknowledges that accumulating PA throughout the week is as beneficial as daily adherence (Bull et al., 2020; Chaput et al., 2020; Hu et al., 2024; White et al., 2022). For example, achieving 60-min of MVPA on 6 days totals 360 min, which closely approaches the weekly target of 410 min, while 7 days exceeds it. This binary classification supports statistical analysis and offers a pragmatic framework for assessing compliance with public health guidelines.

2.3.2. Neighbourhood walkability variables

The study employed the Neighbourhood Environment Walkability Scale for India (NEWS-India), to assess built-environment (BE) characteristics, following previous studies investigating PA in India (Adlakha et al., 2017, 2020; Adlakha and Parra, 2020). Parents completed the NEWS-India questionnaire, which includes eight sub-scales (i) land-use mix diversity (27 items); (ii) land-use access (6 items); (iii) residential density (6 items); (iv) street connectivity (3 items); (v) walking and cycling facility (3 items); (vi) neighbourhood aesthetics (4 items); (vii) traffic safety (8 items); and (viii) crime safety (6 items).

Items were rated on a four-point Likert scale (1 = strongly disagree, 4 = strongly agree). Specific items were reverse coded to ensure directional consistency. The psychometric properties of NEWS-India have been previously established, with intra-class correlation coefficient scores exceeding 0.75 across subscales, indicating excellent reliability (Adlakha et al., 2016).

2.3.3. Socio-demographic characteristics

Parents also reported demographic information, including their age, sex[1], marital status, educational attainment, employment status, as well as the adolescent's age and sex, household monthly income, and vehicle ownership. Parental education was categorised as 'university degree' and 'no university degree'; employment status as 'none or less than part-time'; 'part-time' and 'full-time'. Household income was classified into 'lower-income'; 'middle-income' and 'higher-income' based on the Center for Monitoring Indian Economy (Mahesh, 2022). Vehicle ownership was grouped into three categories: 'no automobile, '1 automobile' and '2 or 'more automobiles'.

2.4. Data processing

To ensure participant anonymity, the data collection instruments refrained from requesting the names of adolescents or parents. Instead, each adolescent-parent pair was assigned a unique identifier code for data storage and analysis purposes. Survey responses were treated as continuous data. To address missing data points, the series mean imputation method was applied at the scale level, replacing missing values using the average score for each item—an approach used in previous studies (Schoeppe et al., 2015; Zhuang et al., 2013). Imputation was conducted using IBM SPSS version 25.

Following initial data cleaning and imputation, analysis of the relationship between PA outcomes and neighbourhood walkability variables revealed a significant skew in the land-use mix diversity sub-scale. This skew appeared to reflect the heterogenous nature of location types included in the sub-scale, which may not align with the socio-spatial realities of Indian cities. Unlike the classic "urban–suburban" model typically found in many Global North contexts, Indian urban structures are shaped by a complex interplay of physical, social, economic, cultural, and behavioural factors. These produce development patterns marked by high degrees of spatial mixing and informality.

A typical Indian city includes diverse zones such as historic cores, unplanned residential clusters, planned commercial hubs, and peri-urban areas where urban and rural characteristics often converge (Tiwari, 2002). Within a single metropolitan region, proximity to essential amenities, services, and recreational facilities can vary significantly across neighbourhoods. Given these contextual specificities, it became necessary to distinguish between different land-use types in the analysis. Accordingly, the land-use mix sub-scale of the NEWS-India instrument was disaggregated into two distinct sub-scales: (1) Land-use Mix Diversity— capturing access to essential amenities and services, and (2) Recreational Facility Score measuring proximity to recreational features such as swimming pools, public open spaces, beaches, lakes, cycling paths, and parks. This refinement aimed to better reflect the unique urban form and lived realities of Indian cities and to provide more context-sensitive insights into how specific built environment features influence adolescent PA outcomes.

2.5. Analytical approach

Fig. 2 outlines the analytical framework employed to achieve the study aim and objectives. Our approach involved two critical methodological decisions: adopting a combined sample analysis and separating socio-demographic variables from perceived walkability assessments. First, our decision to utilize a combined sample, totalling 500 parent-adolescent dyads across the four cities, was driven by considerations of statistical power and reliability. Individual city analyses, each with a sample size of 125, posed challenges in achieving generalizable conclusions due to potential biases and limited representativeness. By aggregating data across cities, we bolster the robustness of our findings, capturing broader trends while mitigating risks associated with small sample bias.

[1] In our research, we define 'sex' as a biological and physical characteristics that differentiate males, females, and intersex individuals.

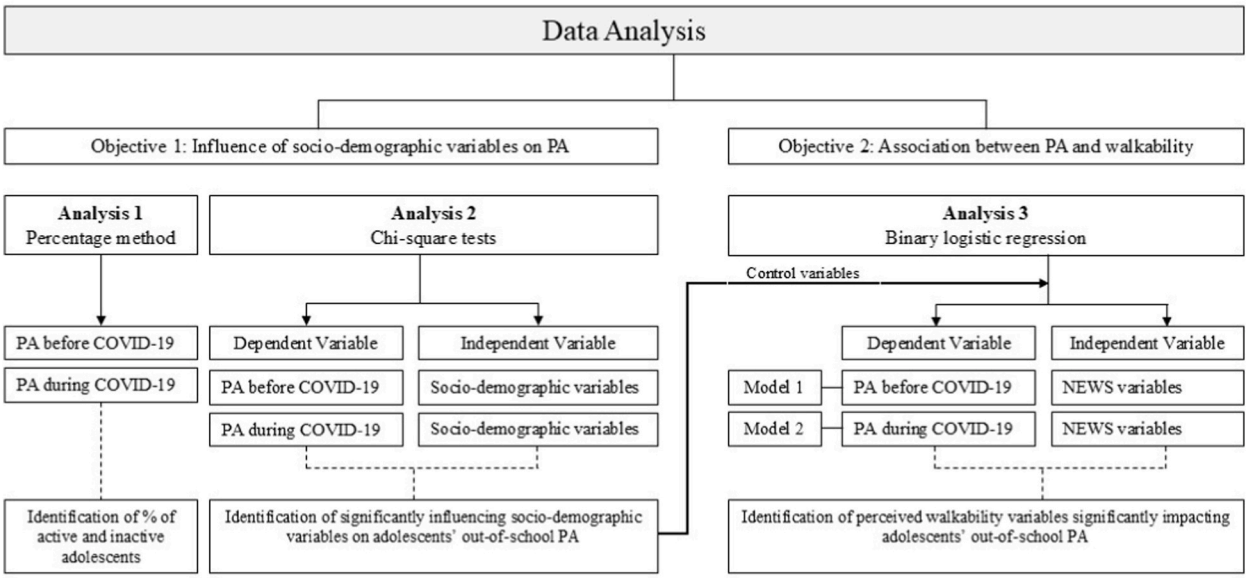


Fig. 2. Analytical framework adopted for the study.

Second, we assessed the influence of socio-demographic variables separately from perceived walkability variables because we intended to isolate and incorporate only those socio-demographic variables that demonstrated a statistically significant impact on PA outcomes into the main model. Including all socio-demographic variables from the outset without prior testing could potentially introduce inaccuracies and confound the interpretation of results. This approach is supported by previous studies which assessed socio-demographic factors as covariates within the primary analytical models (Tyagi and Raheja, 2021; Yu et al., 2017; Zhao et al., 2024). In this way, we maintained focus on our primary aim to elucidate the specific impact of walkability perceptions on adolescent out-of-school PA.

Initially, descriptive analysis was performed to establish a foundational understanding of the sample and its characteristics,

Table 2
Socio-demographic characteristics of adolescents and their parents (n = 500).

Socio-demographic characteristics	N (500)	Percentage (%)
Adolescent's sex		
Boy	228	45.6
Girl	272	54.4
Adolescent's Age		
Younger (11-14 yrs/)	278	55.6
Older (15-18 yrs)	222	44.4
Parent's sex		
Father	69	13.8
Mother	423	84.6
Non-defined	8	1.6
Parent's Qualification		
No university degree	186	37.2
University degree	243	48.6
Unknown	71	14.2
Parent's Employment Status		
None or less than part-time	181	36.2
Part-time	68	13.6
Full-time	251	50.2
Household Income		
Lower income	341	68.2
Middle income	139	27.8
Higher income	20	4
Residence duration in Neighbourhood		
Short duration (<13.5 yrs)	252	50.4
Long duration (>13.5 yrs)	248	49.6
Vehicular Ownership		
No automobile	200	40
1 automobile	212	42.4
2 or >2 automobiles	88	17.6

alongside descriptive statistics of perceived neighbourhood walkability variables. This was followed by Chi-square tests to achieve objective 1-evaluate associations between PA and socio-demographic variables, including adolescent age and sex, parents' education and employment status, and household vehicular ownership. Objective 2 was achieved by employing binary logistic regression analysis, due to the nature of the dependent variable-adolescent's out-of-school PA-which was dichotomized into active and inactive categories, while the independent variables—derived from the NEWS scale were continuous. This choice allowed for the effective analysis of relationships between categorical and continuous data, aligning with methodologies established in previous studies (Consoli et al., 2020; Dias et al., 2020; Yu et al., 2017; Zhao et al., 2024). All statistical analysis was conducted using IBM SPSS Statistics version 25.

Several standard assumptions for binary logistic regressions were tested. Linearity was assessed by examining the interaction between each between neighbourhood walkability variable and its log-transformed values. Multicollinearity was evaluated using tolerance values and variance inflation factors (VIFs). Model fit and robustness were assessed through diagnostic tests including Cook's distance, leverage value, standardized and normalised residuals, deviance values and DFBeta values. In addition, the Independent and Identically Distributed (IID) assumption was satisfied through a randomized, residential address-based sampling design that ensured geographical dispersion. To eliminate intra-familial correlation, recruitment was strictly limited to a single adolescent per household. A p-value threshold of 0.05 was used to determine statistical significance.

3. Results

3.1. Descriptive analysis results

Socio-demographic characteristics of the 500 adolescent-parent dyads are summarised in Table 2. The adolescent sample comprised more girls (54.4%) than boys and predominantly in the 11-14 age group (55.6%). The majority of participating parents were mothers (84.6%), reflecting the strong maternal role in children's everyday lives in the Indian context, as highlighted in prior research (A. Madan et al., 2018).

The distribution of household income was skewed towards lower-income groups, with 68.2% of respondents classified in this category. Despite the economic distribution, nearly half of the parents held a university degree (48.6%), and about half were employed full-time (50.2%). Residential duration in the current neighbourhood was evenly distributed across categories.

A notable 82.4% of households reported owning either no or only one vehicle. Cross-tabulation using Fisher's exact test (due to low cell frequencies) showed a statistically significant association between household income and vehicle ownership ($\chi^2 = 174.02$, $p < 0.001$), indicating clear stratification by income. Specifically, 54.8% of lower-income households reported no vehicle ownership, while 54.7% of middle-income households owned one vehicle, and 90% of high-income households reported ownership of two or more vehicles.

Analysis of perceived neighbourhood walkability variables (Table 3) revealed that parents reported relatively higher perceptions of land-use access (mean = 3.16) and aesthetics (mean = 3.06) compared to other neighbourhood attributes. In contrast, lower scores were observed for walking and cycling infrastructure (mean = 2.61); land-use mix (mean = 2.20) and residential density (mean = 2.22), indicating less favourable perceptions in these domains. While crime safety was rated moderately (mean = 2.64), the high standard deviation (SD = 0.88) suggests substantial variation in parental perceptions of safety. Notably, recreational facilities received the lowest rating among all variables (mean = 1.56), indicating a widespread perception of their inadequacy or absence in the vicinity of respondents' neighbourhoods.

3.2. Adolescent's PA outcome and socio-demographic variables

Table 4 presents the percentages of active and inactive adolescents both before and during the COVID-19 pandemic. Expectedly, even before the pandemic, less than 20% of adolescents were active, aligning with the pre-COVID-19 national data that revealed only 38% of young adolescents and 17% of children were able to achieve WHO-recommended 60 min per day of moderate-to-vigorous PA (Katapally et al., 2016). A qualitative study identified several institutional (inadequate resources, reduced PA opportunities in school, increased academic workload), interpersonal (body image, self-efficacy) and built-environmental barriers (lack of PA-enabled public spaces nearby, safety) as factors contributing to abysmally low PA levels among Indian adolescents (Satija et al., 2018). While during

Table 3
Descriptive statistics of perceived neighbourhood walkability variables.

Built-environment variables	Mean (SD)	Minimum	Maximum
Land-use mix diversity	2.20 (0.56)	1	4
Land-use access	3.16 (0.56)	2	4
Residential density	2.22 (0.60)	1	4
Street Connectivity	2.87 (0.72)	1	4
Walking & Cycling Infrastructure	2.61 (0.85)	1	4
Neighbourhood Aesthetics	3.06 (0.72)	1	4
Traffic Safety	2.86 (0.48)	2	4
Crime Safety	2.64 (0.88)	1	4
Recreational Facility Score	1.56 (0.63)	1	4

Table 4
Percentage of inactive and active adolescents before and during the pandemic.

Duration	% of active adolescents	% of inactive adolescents
Before COVID-19	18.8	81.2
During COVID-19	17	83.0

the pandemic, the further reduction in PA level corroborates with previous national and international study findings (Moitra and Madan, 2022; Rossi et al., 2021; Thapar et al., 2024).

As shown in Table 5, no statistically significant associations were found between adolescents' PA outcomes and their age or sex, nor with parental education or employment status, either before or during COVID-19. However, prior to the pandemic, household vehicle ownership was significantly associated with adolescent's PA (χ^2 (df = 2) = 6.626, $p = 0.036$). Although the strength of the association was weak (Cramer's V = 0.115), the finding suggests that vehicle ownership may play a role in shaping PA outcomes, which is discussed in more detail in the next section. As a result, vehicular ownership was included as a control variable in the logistic regression analysis for pre-COVID-19 data. No significant association was observed between adolescents' PA and vehicle ownership during COVID-19.

It is important to note that although adolescents' sex and age were not statistically associated with their PA outcomes, both were included as control variables in all models before and during COVID-19, consistent with prior well-established evidence (George et al., 2024; Gidlow et al., 2008; Guthold et al., 2020; Hu et al., 2021), identifying them as key determinants of adolescent PA. However, other socio-demographic variables—such as parent's sex, household income, and duration of residence in the neighbourhood—were excluded from the analysis due to limited variability in their distribution, which could introduce bias in the statistical results.

To examined variations in adolescent PA outcomes by household vehicular ownership prior to COVID-19, the data is presented in Fig. 3. The bar chart shows that a higher proportion of adolescents (27.3%) from households with two or more vehicles engaged in out-of-school PA compared to their peers from households with no vehicle or only one vehicle.

3.3. Association between adolescent's PA outcomes with neighbourhood walkability variables before and during COVID-19

Table 6 presents the results of binary logistic regression models for the periods before and during COVID-19. Before the pandemic, traffic safety (OR = 1.70, $p < 0.05$) was the only significant predictor of adolescent's PA; no other neighbourhood walkability variables showed a significant impact. Specifically, higher levels of parental perceived traffic safety were associated with 1.71 times greater odds of adolescents being physically active.

In contrast, during COVID-19, recreational facilities (OR = 0.63, $p < 0.05$) emerged as the only significant factor influencing adolescents' physical activity. Notably, this association was negative, suggesting that the presence of recreational facilities nearby was linked to a higher likelihood of inactivity among adolescents. This finding appears counterintuitive in light of previous literature and is further addressed in the discussion section, with attention to contextual factors unique to India during the COVID-19 pandemic.

4. Discussion

Contrary to several national and international studies, we did not find adolescent age or sex to significantly influence out-of-school PA either before or during the pandemic (Gulati et al., 2014; Kumari et al., 2024; Levi et al., 2024; Ricardo et al., 2022; Rosselli et al., 2020). Among the socio-demographic variables examined, only household vehicle ownership showed a significant positive association with adolescent PA levels prior to COVID-19. A plausible explanation is access to multiple vehicles may have enabled families to transport adolescents to green spaces or organized PA opportunities—particularly important in Indian cities where open green spaces have been steadily declining (Ramaiah and Avtar, 2019).

Access to adolescent-friendly infrastructure such as structured play areas and parks remains limited in Indian cities (Bhor and Mayavel, 2024; Gupta et al., 2016; Kaur et al., 2022). In addition, environmental stressors like extended heat waves and rising air pollution often discourage walking or cycling, prompting caregivers to rely on motorized transport for non-school trips (Patel et al., 2024). As a result, adolescents from households without vehicles face more restricted access to out-of-school PA opportunities, reinforcing a dependence on school-based PA (Satija et al., 2018).

Table 5
Association of adolescent's PA outcome with socio-demographic variables.

S. No.	Socio-demographic variables	Adolescent's PA outcome	
		Before COVID-19	During COVID-19
1	Adolescent's Sex	2.689	2.225
2	Adolescent's Age	0.127	0.380
3	Parent's Qualification	1.482	1.248
4	Parent's Employment Status	0.589	1.533
5	Household vehicular ownership	**6.626**[a]	2.283

[a] Variable is significantly associated with PA outcome ($p < 0.05$).

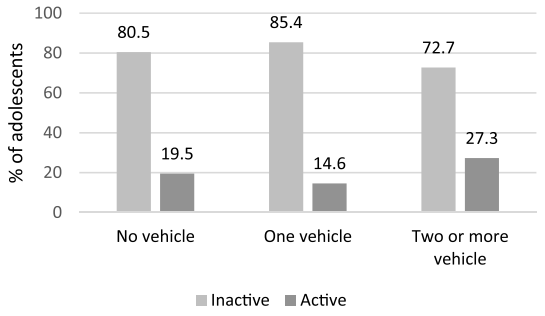


Fig. 3. Variation in adolescent's PA outcome across household vehicular ownership before COVID-19.

Table 6
The association between adolescent's PA outcome and neighbourhood walkability variables.

NEWS variables	Adolescent's PA outcome	
	Before COVID-19[a]	During COVID-19[b]
	OR (95% CI)	OR (95% CI)
Land-use mix diversity	1.12 (0.74, 1.69)	1.20 (0.78, 1.85)
Land-use access	1.31 (0.84, 2.02)	1.42 (0.89, 2.26)
Residential density	1.01 (0.99, 1.04)	1.01 (0.98, 1.03)
Street connectivity	0.96 (0.69, 1.33)	0.95 (0.68, 1.33)
Walking/cycling facilities	0.87 (0.66, 1.16)	1.08 (0.80, 1.46)
Neighbourhood aesthetics	0.99 (0.71, 1.38)	0.85 (0.60, 1.20)
Traffic safety	**1.70** (1.03, 2.80)[c]	1.03 (0.62, 1.70)
Crime safety	0.95 (0.70, 1.27)	1.01 (0.74, 1.38)
Recreational facility score	0.90 (0.62, 1.32)	**0.63** (0.41, 0.96)[c]

[a] $R^2 = 0.031$(Cox & Snell), 0.050 (Nagelkerke). Model chi-square = 15.70, analysis controlled for household vehicular ownership, adolescents' sex and age.
[b] $R^2 = 0.029$ (Cox & Snell), 0.048 (Nagelkerke). Model chi-square = 14.69.
[c] Variables are significantly associated with adolescent's PA outcome ($p < 0.05$).

Given the link between vehicle ownership and household income, our findings suggest that adolescents from higher-income households were more physically active than their lower- and middle-income peers, indicating socio-economic disparities in PA opportunities. While most Indian studies have reported a negative association between socio-economic status and adolescent PA (Bapat et al., 2017; Kumar et al., 2017), or no association at all (Swaminathan et al., 2011), our findings align with a smaller body of evidence showing a positive relationship (Kumar & Kumar, 2023).

Before COVID-19, our analysis identified perceived traffic safety as the only neighbourhood walkability variable significantly associated with out-of-school PA among adolescents across all four cities. This finding partially reflects the traffic-related challenges faced by all four cities, as discussed previously. However, it stands in contrast to studies on Indian adults using the NEWS instrument, which found land-use mix and street connectivity to be the most influential built environment variables associated with PA (Adlakha et al., 2017, 2018; Adlakha and Parra, 2020). Among older adults, walking infrastructure and neighbourhood aesthetics have been shown to have the greatest influence on active lifestyles (Prithviraj and Sundaram, 2023).

This difference is notable as prior studies largely focused on utilitarian PA—walking for work, errands, or caregiving—while our study specifically assessed leisure-time PA undertaken outside of school hours, for recreation, fitness, or socializing. Considering utilitarian PA beyond school among Indian adolescents remains complex, due to poor neighbourhood physical infrastructure, harsh environmental conditions, and importantly, declining parental permission for independent mobility (Tyagi and Raheja, 2021).

Although limited, emerging evidence from India supports the centrality of perceived traffic safety in shaping adolescent PA (Tyagi and Raheja, 2020). Prior studies have highlighted key environmental constraints including distance to school, perceptions of safety, access to play facilities, air pollution, and traffic hazards (Rajaraman et al., 2015; Satija et al., 2018; Tetali et al., 2016). Notably, a micro-scale study in Chennai revealed that beyond the presence of sidewalks, pedestrian crossings were most effective in improving parental perceptions of traffic safety—an important factor in enabling adolescents' mobility (Kingsly, 2019).

Similar patterns have been reported across other Global South settings facing comparable urban conditions. In South Asia, studies from Bangladesh and Pakistan have also identified traffic danger and parental safety concerns as key constraints to adolescents' independent mobility and outdoor PA (Khan et al., 2022; Sukmayasa et al., 2025). In Sub-Saharan African cities such as Lagos and Nairobi, rapid motorisation, inadequate pedestrian infrastructure, and high traffic exposure similarly limit adolescents' walking and cycling opportunities (Oyeyemi et al., 2011). In Southeast Asian cities such as Jakarta, Bangkok, Ho Chi Minh City, informal urbanization and congested road environments further reduce perceived safety and restrict adolescents' active mobility. In Latin

American contexts such as Mexico City and São Paulo, traffic exposure combined with socio-spatial inequalities similarly shapes uneven access to safe outdoor spaces for adolescents (Ferrari et al., 2020; Oyeyemi et al., 2011). These parallels suggest that perceived traffic safety may represent a more generalizable constraint on adolescent PA across rapidly urbanising Global South cities rather than a context-specific finding limited to India.

Our findings also align with international literature. In South Korea, perceived traffic safety negatively affected adolescents' utilitarian walking beyond school zones (Jin et al., 2019). In the US, higher parental perceptions of traffic safety were positively associated with adolescent's self-reported PA in their neighbourhoods (Esteban-Cornejo et al., 2016). In Mexico, this association was significant only among girls, highlighting gendered disparities in mobility and safety (Hermosillo-Gallardo et al., 2020).

That being said, school-built environments have consistently been identified as key enablers of PA among adolescents (Martins et al., 2021). Indian adolescents have self-reported several supportive school-based factors that encourage PA, including more frequent physical training sessions, longer breaks, improved play equipment and facilities, motivated and well-trained teachers, greater opportunities for unstructured play, and the availability of sports camps (Satija et al., 2018). These school-based factors were perceived as more influential than neighbourhood attributes.

This trend reflects the highly structured daily schedules common among Indian adolescents, similar to many of their Asian counterparts (Jin et al., 2019). Societal expectations around academic performance—such as extended study hours and after-school coaching, especially in higher grades—often result in physical education classes being deprioritized in favour of academic preparation for competitive university entrance exams (Pienyu et al., 2024).

As a result, inadequate neighbourhood physical infrastructure, adverse environmental conditions, limited independent mobility, and time constraints due to academic commitments restrict the potential of walkable neighbourhoods to support adolescent PA. This reinforces the role of the school environment as the primary facilitator of PA. However, with COVID-19 related school closures, adolescents lost access to this key space for activity, and were suddenly reliant on neighbourhood environments—previously the least emphasized by caregivers and policymakers in India—as their main opportunity for PA.

Our analysis during the COVID-19 pandemic revealed that recreational facilities had the most significant association with adolescent PA among all environmental variables examined. Interestingly, this relationship was negative, which can be attributed to the widespread closure of recreational spaces during the pandemic (Rawal et al., 2022). The observed negative association, therefore, likely reflects the lack of access to these facilities rather than an adverse effect of the facilities themselves. This finding highlights the critical importance of ensuring the safe and continuous operation of recreational facilities for adolescents during public health crises. Had these facilities remained open, the association would likely have been positive, reflecting their substantial potential to support PA and adolescent well-being. This also highlights the need to differentiate between essential amenities and recreational facilities in future analyses, particularly within the Indian context.

Moreover, access to open and nearby recreational facilities could have served as a key countermeasure to rising screen time among adolescents during lockdowns (Datta and Kundu, 2021; Mahapatra and Sharma, 2021). Increased engagement in screen-based activities was found to be linked with poor dietary behaviours, unhealthy eating habits, and sleep disturbances, and heightened sedentary behaviour and mental stress among Indian adolescents (Gupta et al., 2024; Moitra and Madan, 2022; Rawal et al., 2022).

Building on the literature discussed earlier, our analysis aligns with international findings indicating that adolescents with consistent outdoor access and parental permission were nearly twice as likely to meet PA guidelines (Neville et al., 2022). For example, during the pandemic, Finnish adolescents reported increased PA as they were able to engage in a variety of outdoor activities such as walking, dog walking, dancing, gymnastics, hiking, hula hooping, cycling, frisbee, golf, skating, scootering, and mobile-based PA games—opportunities largely unavailable to many Indian adolescents during that time (Ng et al., 2021). Similarly, in Germany, adolescents, who retained the freedom to participate in unstructured outdoor sports such as jogging, walking, or playing outside alone or with household members showed a notable rise in leisure PA (Schmidt et al., 2020). In Sweden, the decision to keep preschools, playgrounds, and parks open, along with the continuation of organized sports for children, contributed further to maintaining or even increasing PA levels among young people (Delisle Nyström et al., 2020). These international examples emphasize the critical need to preserve avenues for regular movement—especially in times of crisis—given the lifelong physical and mental health benefits associated with sustained physical activity (Neville et al., 2022).

4.1. Policy implications

The findings of this study underscore the necessity of expanding the current policy paradigm beyond a school-centric focus to integrate neighbourhood-scale built environment considerations into India's national adolescent health strategy. As previously noted, while India's National Adolescent Health Program (RKSK-Rashtriya Kishore Swasthya Karyakram) prioritizes non-communicable diseases; it currently lacks a framework to address the influence of the built environment (MHFW, 2014). Similarly, the Urban and Regional Development Plan Formulation and Implementation (URDPFI) guidelines do not explicitly incorporate adolescent-specific needs related to physical well-being (MoHUA, 2015). Although this study represents a preliminary investigation into a multifaceted issue, the emergent evidence provides a compelling rationale for policymakers to harmonize urban development and public health strategies, ensuring they are inclusive and responsive to the diverse needs of India's adolescent population.

4.2. Strengths and limitations

A key strength of this study lies in its use of the NEWS-India scale, adapted for adolescents, to assess PA outside school settings during a global health crisis. The study also benefits from geographical diversity, with data collected from households across multiple

southern Indian cities. Importantly, it is the first study to provide robust evidence on which perceived walkable neighbourhood parameters influence adolescents' out-of-school PA in India—extending the discourse beyond high-income countries.

However, several limitations should be noted. First, the reliance on self-reported data may introduce recall bias. Second, as mentioned previously, the relatively small sample size (125 adolescents per city) of our pilot study limits the generalizability of city-specific findings. Third, the NEWS-India scale was not adapted to address the distinct contextual challenges of each city, which became apparent during data analysis. Fourth, as the data collection occurred during COVID-19 pandemic, reliance on remote contact constrained recruitment. These conditions contributed to a sample disproportionately composed of mother respondents (85%) and low-income households (68%). This imbalance may introduce sample composition bias; we therefore avoid overgeneralization and interpret our findings as most applicable to similar socio-demographic populations.

To address these limitations, future research should implement stratified probability sampling with explicit targets for parents' sex and household income, diversity in recruitment channels, randomize the within-household parent respondent and apply post-stratification weights to improve representativeness. Second, studies should aim to contextualise and expand the NEWS-India tool to better reflect local socio-cultural nuances—for instance, by disaggregating broad categories like walking infrastructure to include specific features such as safe pedestrian crossings. A larger and more diverse sample, including adolescents from small and medium-sized cities, would enhance the generalizability of findings and enable cross-city comparisons. Additionally, combining objective built-environment data with perceived social environment variables would offer a more holistic understanding of neighbourhood influences on adolescent PA. Finally, incorporating interpersonal factors such as adolescents' connection to nature, motivation and viewpoint on PA, and cultural context could provide deeper insights into behavioural drivers of PA.

5. Conclusion

This study is among the earlier attempts to examine the association between adolescent's out-of-school PA and perceived neighbourhood walkability in India. By comparing the empirical findings before and during COVID-19, the study contributes to reorienting the discourse surrounding adolescents' PA and the built environment outside of school settings. Although, the COVID-19-related school closures led to numerous global studies, discussions, and policy guidelines focusing on planning walkable neighbourhoods, open spaces and PA opportunities closer to home, the narrative in India remained unchanged. Given epidemiological predictions that future pandemics of equal or greater intensity are likely, there is a growing urgency to understand how neighbourhood-built environment can support adolescent health and well-being (de Lusignan et al., 2024; Marani et al., 2021).

In this context, we analysed data from 500 adolescent-parent dyads across four Indian cities during COVID-19, revealing two primary findings. Firstly, prior to COVID-19, adolescents in households with vehicle ownership engaged in higher PA levels due to declining availability and accessibility of open spaces, parks, and PA-supportive areas in neighbourhoods, coupled with parental concerns about traffic safety. This suggests that for adolescents living in households without vehicle ownership, schools were the primary venue for achieving the recommended daily PA levels. Secondly, during COVID-19-related school closures, the reliability of school-based PA diminished, underscoring the critical role of continuous availability and access to nearby recreational facilities as the most significant factor influencing adolescent PA.

In essence, schools undoubtedly play a crucial role for adolescent's PA opportunities, particularly in low- and middle-income countries like India. However, our findings suggest that undervaluing the importance of walkable neighbourhoods and local recreational spaces could be a significant oversight. The evidence underscores a critical necessity for neighbourhood-level planning that prioritizes pedestrian connectivity and safe, equitable access to recreational spaces, both in everyday life and during any future crises. Moreover, the findings also call for further research to bridge policy gaps, aiming to establish contextual neighbourhood built-environment guidelines supporting adolescents PA and overall well-being in India.

CRediT authorship contribution statement

Megha Tyagi: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Deepti Adlakha:** Conceptualization, Funding acquisition, Investigation, Supervision, Writing – review & editing. **Laxman Singh Bisht:** Data curation, Validation.

Funding

AHEAD project received funding from the Queen's University Belfast (UK) 2020–2021 ESRC Impact Acceleration Account.

Declaration of competing interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Deepti Adlakha, Ph.D. reports financial support was provided by Queen's University Belfast. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors extend their appreciation to all adolescent participants and their families for their time and valuable contributions to this study. We also acknowledge the efforts of the field investigators and data collection teams in Chennai, Bengaluru, Hyderabad, and Kochi, whose commitment was instrumental in executing the survey, particularly under the constraints imposed by the COVID-19 pandemic.

Data availability

Data will be made available on request.

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