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Can We Walk? Environmental Supports for Active Travel in India

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by

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List of Abbreviations

NCD	Non-Communicable Disease
LMIC	Low-and-Middle-Income Country
PA	Physical Activity
BE	Built Environment
IPEN	International Physical activity and the Environment Network
NEWS	Neighborhood Environment Walkability Scale
IPAQ-LF	International Physical Activity Questionnaire-Long Form
BMI	Body Mass Index
SES	Socio-Economic Status
ICC	Intra-Class Correlation
WHO	World Health Organization
US	United States

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Dedicated to my loving grandparents--

who instilled in me the deep love of learning,

the confidence to explore the world,

and the courage to plunge into many unknowns.

ABSTRACT OF THE DISSERTATION

"Can We Walk?" Environmental Supports for Active Travel in India

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Background: Rapid rates of increase of obesity, diabetes, and associated chronic and co-morbid non-communicable diseases (e.g., cardiovascular diseases and some cancers) are being documented in India, yet in-country evidence-based research of associated risk factors is lacking. Physical activity has been identified as a preventative factor to counter the risk from obesity-related non-communicable diseases. Built environment supports for physical activity represent promising strategies to curb the rise in non-communicable diseases. Mounting research evidence suggests that the built environment can facilitate or constrain physical activity. However, a majority of this research has been conducted in developed nations. Built environment correlates of physical activity that have been documented in developed countries have yet to be studied among low-and-middle-income countries like India. The development and testing of reliable and culturally sensitive measures of built environment attributes is a necessary first step for accurate analysis of environmental correlates of physical activity in low-and-middle-income countries.

Methods: This study systematically adapted and pilot tested the Neighborhood Environment Walkability Scale (NEWS) for India. The adaptation of the NEWS was conducted by Indian and international experts. At baseline, participants (N=370; female=47.2%) from the city of Chennai, India, completed the adapted NEWS-India regarding perceived residential density, land use mix-

diversity, land use mix-access, street connectivity, infrastructure and safety for walking and bicycling, aesthetics, traffic safety, and safety from crime. Modules from the International Physical Activity Questionnaire-Long Form (IPAQ-LF) were used to measure participants' self-reported physical activity, specifically the frequency and duration of leisure-time and travel physical activities. Participants (N=62) were re-tested to evaluate aspects of reliability and validity of the adapted NEWS-India.

Results: The adapted NEWS subscales had moderate to high test-retest reliability (ICC range 0.59–0.91). Residents of high-walkability/high-SES neighborhoods reported higher land use mix diversity, land use mix access, street connectivity, aesthetics, and safety from crime. Residential density and walking/bicycling infrastructure were highest in the high-walkability/low-SES neighborhood. Travel physical activity (PA) was the maximum contributor to total PA in low-SES neighborhoods, while residents of high-SES neighborhoods reported greater levels of leisure-time PA. Sitting time and BMI were greater among high-SES participants. Patterns of PA, sedentary time, and weight status varied significantly by neighborhood walkability and SES. Five of eight built environment (BE) characteristics (residential density, land use mix diversity, street connectivity, aesthetics, safety from crime) were significantly associated with travel PA. There was a two-fold increase in adjusted odds of meeting WHO recommendations of travel PA with greater residential density (aOR=1.9, 95% CI=1.2, 3.2) and land use mix-diversity (aOR=2.1, 95% CI=1.2, 3.6). 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 significantly predicted an increase in adjusted odds of travel PA by approximately two times (aOR=1.9, 95% CI=1.1, 3.1). Results suggest that the relationship between the built

environment and domain-specific physical activity may be context-specific, and that the context in Chennai, India, may differ markedly from that in high-income countries.

Conclusion: The adapted NEWS-India demonstrated acceptable measurement properties among Indian adults and may be useful for evaluation of the built environment in India. Further adaptation and evaluation in other states of India is needed to create a version that could be used throughout the Indian region. The development and testing of reliable and culturally sensitive measures of built environment attributes is a necessary first step for accurate analysis of environmental correlates of physical activity in low-and-middle-income countries, which can inform international evidence-based policies and interventions in the worldwide prevention of physical inactivity.

Chapter 1: Introduction

The rising prevalence of non-communicable diseases (NCDs) like obesity, diabetes, and cardiovascular disease constitutes a significant portion of the growing health burden, of which the greatest increases are expected in low- and middle-income countries (LMICs) across the world.[1] India, a LMIC with a population of 1.2 billion people and soon to be the world's most populous country, is experiencing a NCD epidemic.[2-5] Currently, India has the largest diabetic population in the world, with 33 million in 2015, projected to reach 130 million by 2030.[6, 7] Cardiovascular disease is the leading cause of death in India, and its contribution to mortality is rising; deaths due to cardiovascular disease are projected to increase from 2.7 million in 2004 to 4.0 million in 2030.[6, 8, 9, 4610] Morbid obesity [body mass index (BMI) >30 kg/m^2] is currently affecting 5% of Indians (approximately 61 million people).[11] 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.[12] NCDs currently account for 53% of the total deaths and 44% of disability adjusted life years lost in India. Projections indicate a further increase to 67% of total deaths by 2030. Despite such alarming statistics, there is minimal research examining the rising prevalence and risk factors causing NCDs in the general population of India.

Calls to reduce global epidemics of NCDs by the United Nations and the World Health Organization have recommended increasing physical activity (PA)* as a key strategy.[6, 13-15] In 2011, the United Nations High-level Meeting on Non-Communicable Diseases identified increasing PA as one of five priority intervention areas to reduce the impact of NCDs, noting

* Physical activity (PA) is defined as any bodily movement produced by skeletal muscles that requires energy expenditure. Walking, running, dancing, swimming, yoga, and gardening are a few examples of PA. Global guidelines on PA for health recommend that among adults aged 18–64 should engage in at least 150 minutes of moderate-intensity aerobic physical activity throughout the week, or at least 75 minutes of vigorous-intensity aerobic PA throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity.

modification of the built environment (BE)[†] to support PA as a key focus area.[16] The role of environmental and policy strategies to increase PA at a population level has recently received attention, with calls for further evidence on the most relevant and potentially modifiable BE attributes.[17]

Mounting research evidence suggests that the BE can facilitate or constrain PA.[18-30] BE's that are PA friendly depend upon an appropriate integration of land use and transportation infrastructure, including higher densities, a mix of residential and commercial land use, connected systems of sidewalks, bicycle lanes, greenways, and public transit. [31-33, 34] For example, measures of land-use mix, residential density, street connectivity, and street intersection density have been positively related to minutes of moderate PA per day.[35] Presence of sidewalks, crosswalks, bicycle lanes, bus shelters, and access to public transportation (e.g., bus rapid transit, light rail) has been linked to increased levels of PA during travel.[22, 36] Studies have demonstrated that individuals in more walkable, mixed-use, and transit accessible neighborhoods tend to walk or bicycle more and have a lower likelihood of obesity compared with those in automobile-dependent neighborhoods.[36-39]

However, studies examining PA and BE associations thus far have been primarily limited to Australasia, Europe, North America, and South America.[40-42] Findings from these studies may not generalize to other parts of the world, particularly in LMICs like India that are collectively home to 80% of the world's population and are at higher risk for developing NCDs.[1, 43, 44] The BE in many LMICs is distinct in terms of development patterns and different from those in the developed countries. Rapid, unplanned, and unsustainable urban development are making

[†] The built environment (BE) refers to physical surroundings, buildings, and infrastructures (e.g., homes, schools, workplaces, parks, streets, etc.) designed or modified by humans.[14-16] Dimensions of the BE include buildings and parks at the lower end of the spectrum, to neighborhoods and cities at a larger scale encompassing supporting public infrastructure, such as water supply, sewer systems, transportation systems, or energy networks.

LMICs key focal points for emerging environmental and health hazards. These hazards include the synergistic problems of urban poverty, traffic fatalities, and air pollution. In addition, increased urbanization and motorization and diminishing space for walking/recreation in cities is associated with more sedentary lifestyles and a surge in related NCDs.

Due to these BE differences, questions remain about the applicability of surveys constructed in developed countries to the local contexts in LMICs. To address this issue, there have been recent calls for investigators to collaborate on a regional basis to adapt BE measures that are tailored to the LMIC contexts.[45, 46]

For the purposes of this dissertation, the World Bank's main criterion for classifying world economies by gross national income per capita[‡] is used to identify LMICs. LMICs are also referred to as developing or rapidly urbanizing economies. In this dissertation, the terms *LMICs* or *developing countries* or *rapidly urbanizing economies* are used interchangeably.

1.1 Significance for India

India is experiencing dramatic urban growth with implications for social, economic, and ecological sustainability.[47, 48] The pace of urbanization has outpaced the development of basic public health services and regional infrastructure, compounding health threats from NCDs.[48, 49] Along with poor health outcomes, issues of pedestrian safety, air pollution, and increasing carbon emissions are especially challenging to adapt to in urban environments already facing disparities across religious and socio-economic lines.[50-53] While the consequences of urban living

[‡]For the current 2016 fiscal year, low-income economies are defined as those with a gross national income (GNI) per capita, calculated using the World Bank Atlas method, of $1,045 or less in 2014; middle-income economies are those with a GNI per capita of more than $1,045 but less than $12,736; high-income economies are those with a GNI per capita of $12,736 or more. Lower-middle-income and upper-middle-income economies are separated at a GNI per capita of $4,125. These operational guidelines were established based on the view that since poorer countries deserve better conditions from the Bank, comparative estimates of economic capacity needed to be established.

may be exposed through a population's health, the underlying causes or amplifications of health problems are often rooted in conditions best addressed through non-public health pathways such as neighborhood design and planning, as explored in this study.

1.2 Rationale and Research Gaps

A large and continually expanding body of research from developed nations has shown the way cities and neighborhoods are planned and managed can make a substantial difference to the health of their residents.[31, 33, 40, 54] However, existing literature on NCD prevention and control through urban planning is non-existent in India. The identification of specific neighborhood factors that influence NCDs remains under-explored. Wide variations in patterns and characteristics of Indian BEs along with a rapid rate of urbanization calls for an in-depth exploration of neighborhood design impacts on NCD outcomes in India.

To date, there is no literature that documents relations between neighborhood walkability, BE variables, and PA in India.[2] Studies on PA in India are minimal, and do not provide definitive explanations. From a PA and public health perspective, these studies have numerous shortcomings: the contribution of community design to overall PA is unknown, neighborhood environment variables have not been studied, and reliable and valid measures of environmental variables tailored to the Indian context have not been used in these studies. Further investigation of the environmental correlates of PA is needed and could lead to improved interventions for Indian contexts.

1.3 Research Questions

This dissertation probes the question of how the BE, including density, land-use mix, and elements of design (including bikeway and sidewalk facilities), pedestrian safety, and crime influence PA behaviors. This study applies an interdisciplinary framework from the fields of

public health and urban planning, with the goal of analyzing neighborhood BE supports for promotion of healthy, active, and safe living in India. The overall goal of this study is to understand the characteristics of BEs and its associations with PA.

This study adapts a self-report measure of neighborhood environments for India—Neighborhood Environment Walkability Scale[55, 56] (hereafter called NEWS-India)—and its variables hypothesized to be important facilitators of PA. The study compares PA across two major life domains or life areas—travel and leisure—among adult residents living in neighborhoods stratified by neighborhood walkability and socio-economic status (SES) in the city of Chennai (formerly Madras) in India. 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 PA and BE's. A major goal of IPEN is to represent the worldwide variation in BE's.

This study attempts to answer the following research questions:

(1) Do relationships established between the built environment and physical activity in the developed nations also hold for cities in the developing world, such as Chennai, India?

(2) How does land use, street connectivity, and built environment infrastructure (e.g., sidewalks, crosswalks, bicycle lanes, parks, etc.) impact domain specific physical activity (travel, leisure) outcomes in Chennai, India?

(3) How do intrapersonal factors (e.g., age, gender, religion, caste, and socioeconomic status) modify the associations between built environment features and domain specific (travel, leisure) walking in Chennai, India?

1.4 Specific Aims

Aim 1: Systematically adapt a self-reported instrument—Neighborhood Environment Walkability Scale (NEWS)—to measure built environment characteristics relevant for physical activity in India.

Rationale: Measures of the built environment have been created in developed countries and may have limited applicability in LMICs like India. The built environment in India is distinct in terms of development patterns and different from those in the developed countries, necessitating the need for a culturally appropriate measure.

Aim 2: Evaluate aspects of reliability and validity of the adapted NEWS among adults in India.

Rationale: The NEWS was developed in the United States, and its applicability to other environments may be limited due to differences in culture and environmental features.[57, 58] Testing the reliability and validity of NEWS-India is a necessary first step before the measure can be used to adequately evaluate PA and BE associations in India.

Aim 3: Examine the relationships between built environment features and physical activity (leisure, travel) and variations by socio-economic status.

> **Hypothesis 3.1:** Leisure physical activity will be lower in low-SES populations compared to higher-SES populations.
>
> **Hypothesis 3.2:** Travel physical activity will be greater in low-SES populations compared to higher-SES populations.

Rationale: Despite rapid economic progress in recent years, many Indians struggle on a daily basis to make ends meet—over half of the city's households live below the poverty level.[59] For many, walking and bicycling are likely necessities, regardless of urban environments. Thus, the premise that the design of cityscapes significantly influences leisure and travel PA might not

hold for significant segments of society in Indian cities like Chennai. And if it does, the relationships established in modern advanced societies might be fundamentally different in poorer urban settings. Studies show that poorer individuals tend to walk less for leisure and recreation and more for utilitarian travel purposes (e.g., going to work or shopping) in developing countries, such as in Brazil.[60, 61] However, few studies have examined the effects of demographic factors (SES, income, education, etc.) on PA in India.

Aim 4: Community and street-scale urban design features will have a stronger association with physical activity than residential density and land use mix.

Rationale: In the absence of strict enforcement of land-use regulations (e.g., zoning), the city of Chennai like many other cities in the developing world, has evolved to accommodate both foot and bicycle travel.[61] Compact, mixed-use development that allows many destinations to be quickly and conveniently reached by foot, bicycle, or public transit is more the rule than the exception. Consequently, there might not be enough variation in the density, land-use mix, and urban design profiles of neighborhoods to discernibly influence residents' PA choices. Instead, street-scale urban design features (e.g., sidewalks, crosswalks) and socio-demographic factors (e.g., income, car ownership levels) might be stronger determinants of leisure and travel PA.

1.5 Significance and Innovation

This project is significant by addressing health behaviors from an interdisciplinary perspective in a rapidly urbanizing Indian context where chronic NCD prevention remains understudied. The research is innovative by examining the two most common domains (leisure and travel) that are primary contributors to total PA and where physically active lifestyles are known to vary by purpose and context.[62-64]

To the study investigator's knowledge, there has been no research estimating neighborhood BE variables and PA prevalence in India. This study is among the first to examine correlates of BE and domain-specific PA in India. This project is original, novel work to advance the current state of urban planning and public health research by identifying modifiable environmental determinants of chronic diseases in India. By leading the adaptation and development of NEWS for India, this study is foremost in establishing a measure for BE assessment for Indian contexts. This research presents seminal work to launch the field of active living research in India. Knowledge gained from this study will lead the creation of BE and PA research in India. Overall, this study has tremendous potential to extend and increase the current state of BE-PA research evidence for NCD prevention in LMIC contexts.

Chapter 2: Background and Scope of the Problem

The rise of NCDs and their impact in LMICs has gained increased attention in recent years. NCDs are now the leading cause of global mortality, accounting for over 60% deaths worldwide. Nearly 80% of the yearly NCD deaths, equivalent to 29 million people, are estimated to occur in LMICs.[65, 66] This reflects both the size of the populations in LMICs and the epidemiologic transition from infectious to chronic diseases.[44, 67, 68] However, the explanation for this rise is mostly an extrapolation from the history of high-income countries whose experience differed from the development processes affecting today's LMICs.

This chapter appraises these differences in context to gain a better understanding of the epidemic of NCDs in LMICs. Lifestyle changes due to urbanization and changes in the BE are highlighted. The role of PA as a preventative factor to reduce population risk and individual susceptibility to NCDs is discussed. Finally, a summary of PA and BE research from India is provided.

2.1 Epidemiological Transition and Lifestyle Changes in Low- and Middle-Income Countries

Historically, communicable diseases[§] posed a major public health hazard. However, in the 20th century, scientific and technological advances have checked the prevalence of communicable diseases. The discovery of antibiotics, improvements in health care, implementation of vaccination programs, enhanced sanitation and hygiene have reduced the spread of communicable diseases.[43] Even so, the risk of developing NCDs is on an upsurge, of which the greatest increases are expected in LMICs across the world.[1] The changing patterns of population

[§]An infectious disease transmissible from one person to another. Causative agents include microbes such as bacteria, viruses, parasites, and some fungi. Examples of communicable diseases include pneumonia, tuberculosis, diarrhea, influenza, measles, malaria, etc.

age distributions, mortality, fertility, life expectancy, and causes of death due to shifting disease burdens have been termed the epidemiological transition.[68-70]

This epidemiological transition—the change from a burden of disease dominated by mortality from infectious causes to degenerative or chronic causes[69]—currently being experienced in LMICs is compressed into a shorter time frame than that experienced historically in high-income countries. Furthermore, developing countries not only have to deal with their current burden of infectious diseases and ill-functioning health systems, but also with the growing burden of chronic diseases,[71 72, 73] a situation that has been described as 'a race against time'.[74]

Until recently, the NCD burden that was widespread only in developed nations has shifted to a LMIC context. NCDs have become dominant sources of morbidity and mortality in LMICs and have been termed "lifestyle diseases" of the 21st century. This rise in NCDs has been attributed to changes in the BE, rapid urbanization, increased mechanization, and technological advancements that have greatly altered the quality of life.[31, 48, 54] The ways in which people now move to and at work (be it market, workplace, or home production), shopping, leisure, and travel have shifted noticeably over the past several decades, resulting in increased sedentary behaviors or time spent sitting.[75, 76] These lifestyle modifications have led to marked shifts in energy imbalance and new patterns of PA that are spawning the rise of NCDs. [29, 33, 77, 78] This sum of influences that the surroundings, opportunities, or prevailing conditions of life have on promoting obesity in individuals or populations has been termed obesogenic, and has not yet been fully understood in the context of LMICs. Section 2.2 below provides a general overview of the four major domains of PA—domestic, occupational, travel, and leisure—based on research in developed countries and LMICs.

2.2 Physical Activity Domains

Physical activity has been identified as a preventative factor to counter the risk from NCDs.[44, 65] Research on PA has delineated four major domains of PA, i.e., areas of life in which activity is done according to purpose and context: (1) at home or domestic PA which includes household chores requiring movement, such as cleaning and gardening, (2) at work or occupational PA, (3) while commuting or active transportation which includes walking and bicycling for travel, and (4) for leisure or recreational purposes including both exercise and sport, referred to as leisure-time PA.[79] Among these four domains, leisure and travel domains are the primary contributors to total PA levels in developed countries.[80, 81]

2.2.1 Domestic Physical Activity

Recent developments in the study of energy expenditure of domestic activities have highlighted the potential contributions of these activities to health. Vigorous household chores requiring movement, such as cleaning, and gardening activities may be the major source of energy expenditure for certain population groups (e.g., women). Performing these vigorous domestic activities can add up to reach the overall prevalence levels of adults meeting the recommended PA guidelines, particularly women.[82] Studies have demonstrated that the inclusion of domestic activities increases the prevalence of engaging in sufficient PA by 12%.[83] Men and women aged over 30 years have reported participating in significantly more domestic activities than their younger counterparts.[83] Evidence on the health benefits of domestic PA has remained inconclusive because domestic activity is analyzed as part of overall lifestyle activity, making it difficult to disentangle its independent effects.[84] Future assessments of domestic activities in estimating total PA levels in the population should not be dismissed given the current public health emphasis on promoting active lifestyles. Measurement of domestic PA can play an

important role in the estimation of total PA in LMICs. This is because domestic duties are often divided along gender lines in many LMICs and many wealthier households employ servants or domestic helpers, particularly to do the heavier work.[85]

2.2.2 Occupational Physical Activity

Occupational or work-related PA refers to bodily movement to perform job tasks in workplaces.[86-89] The time frame for OPA is usually considered as an 8-hour work day.[89] Historically, many adults engaged in PA as part of their jobs. As work in today's society becomes increasingly sedentary due to mechanization and technological advancements, levels of occupational PA have decreased substantially.[90] Consensus on survey questions to track occupational PA has been lacking. Studies have tracked occupational PA in a variety of ways, ranging from job titles and classifications of job activities according to their energy cost, to self-report measures.[91-93] However, given the development and implementation of work-related labor saving devices in numerous industries, assessment of occupational PA based upon job titles and job activities is becoming increasingly obsolete.[89]

More recent occupational PA studies have focused upon questionnaires that measure frequency, intensity and duration of activities performed.[94] Montoye et al. (1996) reviewed the different approaches that have been used to obtain information about occupational PA and found a variety of survey questions being asked of participants.[95] In view of the limitations of these self-report measures there has recently been a call for the inclusion of a combination of self-report and objective measurements in future surveys of occupational PA.[96-98] While most studies agree that occupational PA has some protective effect against NCDs and all-cause mortality, the data remain controversial, with some studies showing negative associations between occupational PA and various health outcomes.[89, 99, 100] What remains clear is that excluding measures of

occupational PA may result in significant underestimations of PA in many employed adults.[101-104]

2.2.3 Travel Physical Activity

Walking, bicycling, and other non-motorized means of travel comprise a major form of PA worldwide and have been collectively referred to as 'active transportation' or 'active travel' or 'active commuting'. Common destinations for active travel include workplaces, retail stores, restaurants, institutions such as schools, churches, or government agencies, entertainment establishments, and other social gathering places. Such activities can meet daily recommendations for PA.[105-107] However, transportation research in the United States (US) shows that over 75% of all trips less than 1 mile (prescribed walkable distance is 1/4-1 mile) are made by automobile.[108-110] In addition, the number of walking trips as a percentage of all trips taken has declined over the years. Walking trips made by adults dropped from 9.3% in 1977 to 7.2% in 1990 and again to 5.4% in 1995.[108, 110, 111]

In The Netherlands, Denmark, Sweden, parts of Finland, and in many LMICs, bicycling to work, school, or to run errands still remains commonplace. LMICs like India suffer from fundamental issues where overcrowded street conditions, an absolute neglect or lack of BE infrastructure, and poor enforcement of traffic rules and regulations fails to support and encourage active commuting behaviors. Reversing the decline in rates of walking and bicycling for travel related purposes, especially for short trips, presents a major opportunity for improving health among children, adolescents, and adults, worldwide. Recent research has focused on BE factors that could support active travel as part of a healthy lifestyle.[109] Public health experts contend that substantial changes in the BE are needed if walking and bicycling are to become widely accepted options. For example, the provision of sidewalks, crosswalks, and dedicated bicycle lanes on

major roads, introduction of traffic signals for pedestrians, bicyclists, and the use of traffic calming devices is known to increase active travel.[22] However, most of this evidence on active travel is from developed countries. With the exception of some LMICs in South America, no data are available from LMICs in Africa and central Asia. Overall, data on active travel in LMICs are scarce.

2.2.4 Recreational or Leisure-time Physical Activity

Leisure-time PA is a broad descriptor of participation in PA during free time, based on personal interests and needs. These activities include formal exercise programs, sport, dance, as well as walking, hiking, running, bicycling, etc., for recreation.[112] Exercise (or exercise training) is a key subcategory of leisure-time PA in which planned, structured, and repetitive bodily movements are performed over an extended period of time to improve physical performance in sport, or maintain one or more components of physical fitness. Sport, as typically defined, involves competition, and can be performed either individually or in groups.

Historically, engagement in PA among many adults was a default outcome of labor-intensive activities at the workplace. As a result of segregated land use and increasingly sedentary jobs more recently, PA has become largely recreational and more often occurs during leisure time, as budgets and time allow. Venues for leisure-time PA include schools, homes, residential neighborhoods, public parks, streets, health centers, fitness clubs, as well as public and private recreation centers. By definition, engagement in leisure-time PA occurs during people's discretionary time; therefore personal choice with conscious intention and purposes for leisure-time PA are assumed. In addition, although intensity and duration of leisure-time PA can vary, the common element across these activities is resultant substantial energy expenditure.

Studies on environmental correlates of PA have found that leisure activities are consistently related to transportation infrastructure in the BE (e.g., sidewalks, safety of crossings), to aesthetic variables (e.g., greenness, rated attractiveness), and to proximity to recreation facilities and locations.[41] Leisure-time PA is the predominant contributor to total PA in high-income countries, compared to LMICs, making it the most researched domain of PA.[113-115] Some studies in the US have estimated contribution of leisure-PA to total PA to be almost 50%. An understanding of environmental correlates of leisure-time PA in LMICs is urgently needed to support the development of interventions to reverse the rapidly changing determinants of inactivity occurring through urbanization, passive entertainment, and motorized transport.

2.3 Multilevel Influences

Ecological models of health promotion suggest that human health is determined by many factors outside the biomedical domain, even with the restricted definition of health as the absence of disease.[18, 116] Much recent research evidence reveals that NCDs can be moderated by how we design and build our immediate environment.[54] The built environment (BE) refers to physical surroundings, buildings, and infrastructures designed or modified by humans.[29, 117] The Guide to Community Preventive Services (Community Guide)[118] currently recommends the following BE interventions to increase PA and reduce obesity: (1) community, street-scale urban design and land use policies; (2) creation of, or enhanced access to places for PA; and (3) transportation policies and practices. Although studies show a consistent correlation between neighborhood deprivation and prevalence of obesity, diabetes, and other NCDs in the US, UK, and Australia, the effects of the above-mentioned BE features have not been examined in India.[48, 119] Such studies can begin to help us understand how physical neighborhood disparities affect chronic health outcomes in LMIC contexts.

2.4 The Indian Context

2.4.1 Urbanization in India

Throughout its history, the largest percentage of India's population has lived in rural areas, but this is rapidly changing as the country is experiencing large scale urban growth. India's urban areas are growing much faster than estimated previously, adding 90 million new residents in the last 10 years. By 2030, Indian cities are projected to be home to another 250 million people.[120] The 2011 census in India showed that for the first time since India's independence in 1947, the absolute increase in population in urban areas was more than in rural areas; the level of urbanization increased from 27.81% in 2001 census to 31.16% (377 million people) in 2011 census whereas the proportion of rural population declined from 72.19% to 68.84% (833 million people).[59,120] Rural areas adjacent to India's major metropolitan cities are witnessing faster economic growth and generating higher employment than the mega-cities. Access to–and the quality of–water, sanitation, and electricity are much worse in the urban periphery than at the core.

Transportation costs between the metropolitan cores and the peripheries are among the highest in the nation. There was a 38-fold increase (3 to 115 million) in the number of registered motor vehicles in the country between 1981 and 2009.[121] Successive governments have prioritized investment in road infrastructure, while planning for urban growth at the local level has generally been weak and haphazard. In combination, these factors have resulted in urban BE's with inadequate development of any public transport infrastructure and hazardous conditions for walking and bicycling in most Indian cities and towns.[122] Efforts to increase active travel face a number of these powerful countervailing influences in India. A notably large number of people live in underprivileged neighborhoods with conditions that offer less support and fewer

opportunities for PA because the BE is unattractive and/or unsafe due to high traffic volumes, poor infrastructure, and crime. There are fewer locations in which to exercise or engage in any form of PA, such as parks, playgrounds, greenways, or trails.

Overall, Indian urban environments are distinct in terms of developmental patterns and are different from those in the developed countries. Neighborhoods in India are characterized by diverse terrains, land uses, infrastructures, transportation, and road designs that may not be adequately captured by measures constructed in the developed countries.

2.4.2 Summary of Evidence from India

Patterns of industrialization in India have resulted in a shift in work patterns for a substantial proportion of the population, from high-energy expenditure activities such as farming, mining and forestry to less energy-demanding jobs in the service sector.[123] Sedentary lifestyles with a rise in car and computer use and a higher fat diet dominated by more refined foods are being observed.[1, 116, 123, 124] These changes have resulted in a substantial increase in NCDs in India.

The most recent systematic review of published studies by Ranasinghe et al. (2013) that reported PA among South Asian adults found eight peer-reviewed research articles and two reports of the World Health Organization (WHO)-STEPS survey for NCD risk factors in India.[2] All studies examined in the systematic review were conducted during 2003–2011 and reported on the PA levels among adults in South Asia. From these studies, the overall prevalence of physical inactivity in India ranged between 18.5% and 88.4%. In Indian males the prevalence of inactivity was 12.7%-66.2%. Majority of the studies (n=5, 62.5%) reported a prevalence of inactivity less than 23% in Indian males. In Indian females, the inactivity prevalence was 17.0%-79.6%, while majority of the studies (n=5, 62.5%) reported it to be greater than 39.5%. The prevalence of inactivity in urban areas of India was reported as 20.7%-88.7%, while in rural areas it was 6.6%-

88.1%. One study conducted in rural India reported that physical inactivity was more at leisure time (males-85.2%, females-97.3%), and at work (male-57.2%, female-59.9%) and less during travel (male-18.8%, female-45.7%).[125] A similar study in both urban and rural areas of India reported inactivity more at leisure time (74.0%) and less at work (31.0%).[126] None of these studies examined impacts of the BE on PA levels.

Ranasinghe et al. (2013) cite several socio-economic factors associated with physical inactivity. Skilled workers and professionals were more inactive than unskilled workers.[126] Similarly, higher education was a significant factor associated with physical inactivity.[127] Gender is an important factor to determining PA levels with higher physical inactivity prevalent among women.[127 125, 128-130] Studies have also reported that Indians engaging in recreational exercise were inactive in other domains.[131]

To date, there has no comprehensive assessment of BE impacts on PA levels in India. Only one recent cross-sectional study has accounted for active travel and associations with NCDs among adults in India.[122] Millet and colleagues (2013) examined travel mode (walking, bicycling, and public transport) and duration of travel to work in rural and urban India using data from the Indian Migration Study (n=3,902) conducted during 2005-2007. Associations between active travel and cardiovascular risk factors were assessed using random-effect logistic regression models adjusting for age, sex, caste, standard of living, occupation, factory location, leisure PA, daily fat intake, smoking status, and alcohol use. Their study found evidence of a dose-response relationship between duration of bicycling to work and being overweight, having hypertension or diabetes. Rural dwellers were significantly more likely to bicycle (68.3% versus 15.9%; $p<0.001$) to work than urban dwellers. In participants who travelled to work by private transport, public transport, bicycling, and walking, the prevalence of overweight or obesity was 50.0%, 37.6%, 24.2%, 24.9%;

hypertension was 17.7%, 11.8%, 6.5%, 9.8%; and diabetes was 10.8%, 7.4%, 3.8%, and 7.3%, respectively. Participants walking or bicycling to work were significantly less likely to be overweight or obese than those travelling by private transport. Those bicycling to work were significantly less likely to have hypertension or diabetes. These findings are consistent with a growing evidence base derived from studies conducted in high-income settings and upper middle-income countries where active travel to work has been associated with significant decreases in NCDs. Millet et al. (2013) suggest that increasing active travel could be important in restraining the increase in overweight and obese adult populations in India in the next two decades. The study also highlighted the high percentage of urban respondents using private transport for commuting (45%) which is reflected in the recent dramatic growth in car and motorbike ownership and lack of investment in public transport infrastructure in India. Higher rates of car usage and ownership have also been reported in LMICs like Argentina, Brazil, Mexico, and China.[132]

Studies in the US and Latin America have shown differences in levels of walking and bicycling by socioeconomic status.[65, 114, 115, 133, 134] Walking and bicycling have been the primary modes of transportation among the Indian poor and/or rural populations, but socioeconomic differences in transportation mode choice and impacts on PA have not been investigated in India. The likelihood that people of higher socioeconomic status who currently rely on private automobiles will revert back to walking, bicycling, or active commuting remains to be explored.

Specific barriers to increasing PA in India include environmental factors such as heat, inadequate urban infrastructure, pollution and other hazards. Patterns of PA have been inadequately studied in India. Research into correlates of PA (factors associated with PA) or determinants (those with a causal relationship) of PA has been slow. Further, the impacts of the BE on PA have not been considered. Cultural adaptation of environmental measures constructed elsewhere is required as a

first step before such measures can be used to adequately evaluate PA and BEs in India. Further research evaluating the impact of interventions to increase active travel in India and other LMICs is warranted.

Chapter 3: Theories and Conceptual Frameworks

Previously, most of the PA studies conducted by public health and behavioral scientists assessed only recreational or leisure-time PA. In the late 1990s, public health professionals discovered that professionals from other disciplines were also interested in PA and its promotion across different domains of everyday life. Transportation planners, urban planners, and urban designers had been studying how to design cities so people would walk and cycle more.[29] They were interested in walking and bicycling for transportation to ease traffic congestion, reduce air pollution, and enhance a sense of community. They studied PA completed as a necessary component of transportation, which was distinct from the leisure-time activity studied by health professionals.[79, 135] As the data, concepts, and methods from the planning and transportation fields have been integrated into public health, opportunities for promoting PA expanded again. "Active living" is a broader concept that incorporates exercise, recreational activities, household and occupational activities, and active travel.[135] The change in terms from exercise to PA to active living symbolizes the evolution in how PA is conceived, in disciplines engaged, and in conceptual models used to guide research, policy, and practice.[79]

The premise of this chapter is that multilevel interventions based on ecological models and targeting individuals, social environments, physical environments, and policies must be implemented to achieve population change.[18, 79, 136] Multilevel research and interventions require multiple disciplines to combine their concepts and methods to create new transdisciplinary approaches. The application of multilevel models and transdisciplinary methods to promote active living is in its early stages but is expanding rapidly. For progress to be made, the ability of multiple disciplines to contribute to research, practice, and policy change must be better understood. This chapter describes a model of active living as described by Sallis et al. (2006),

outlines the socio-ecological framework and contributions being made by selected disciplines (urban planning, sociology, and criminology), and proposes methods of research and intervention informed by transdisciplinary collaboration.

Theories and models that specify psychological and social influences on human behavior have been the dominant frameworks for PA research and practice. Applications and use of the Health Belief Model, Theory of Planned Behavior, Social Cognitive Theory, and the Transtheoretical Model[137] have led to an almost-exclusive focus on interventions that target individuals or small groups. Though these models have led to effective interventions[138, 139], important limitations of the models and resulting interventions are apparent and are necessary to highlight here. First, effect sizes for many types of PA interventions are small to moderate.[140] Second, recruitment rates to programs tend to be modest. Third, maintenance of PA following programs is poor.[141] Programs and interventions with moderate and temporary effects that reach small numbers of people have been unable to create population-wide increases in PA. There is growing interest in ecological models as a more productive framework for PA promotion.

In public health, ecological models refer to people's interactions with their physical and sociocultural surroundings.[142] Ecological models are distinguished by their explicit inclusion of environmental and policy variables that are expected to influence behavior. Rather than positing that behavior is influenced by a narrow range of psychosocial variables, ecological models incorporate a wide range of influences at multiple levels.[18, 143] Levels of variables often included in ecological models of PA include intrapersonal (biological, psychological), interpersonal/cultural, organizational, physical environment (built, natural), and policy (laws, rules, regulations, codes). Psychosocial models can be integrated into ecological frameworks to provide specific hypotheses for a given level, such as intrapersonal.

A key precept is that interventions will be most effective when they operate on multiple levels.[79, 144] According to ecological models, the most powerful interventions should: (a) ensure safe, attractive, and convenient places for PA, (b) implement motivational and educational programs to encourage use of those places, and (c) use mass media and community organization to change social norms and culture.

Ecological models were the basis for the Institute of Medicine Report on Health and Behavior[145] and Leading Health Indicators for Healthy People 2020[146], and have been widely used across several studies. Numerous authors have identified environmental and policy interventions as the most promising strategy for creating population-wide improvements in eating, PA, and weight status.[147-153] Environmental and policy changes are the primary strategy proposed for obesity control by the World Health Organization[154], the Institute of Medicine report on preventing childhood obesity[155], and the Centers for Disease Control and Prevention.[156] Ecological models are particularly well suited for studying PA, because PA is done in specific places. Studying characteristics of places that facilitate or hinder PA, therefore, is a priority.

Ecological models direct attention to environmental and policy factors that may be root causes of the epidemic of sedentary lifestyles.[157] Trends that produced extensive use of cars and electronic entertainment, zoning codes that require building auto-dependent suburbs, limited investment in pedestrian and cycling facilities, computer-centric work environments, proliferation of labor-saving devices, and fire codes that require stairways to be closed are plausible explanations of the development of sedentary lifestyles. Population-wide declines in knowledge, self-efficacy, enjoyment, and social support related PA are much less plausible explanations.

Linking Theoretical Frameworks - Public Health and Urban Planning

Growing emphasis on promoting environmental change as a means to increase PA has motivated conversation and collaboration between researchers and practitioners in the fields of public health and urban planning. Although these fields share similar objectives, their theoretical and methodological approaches for examining the association between the environment and behavior often differ in significant ways.[158] Hoehner and colleagues highlight the importance of linking conceptual frameworks and theories in public health, urban planning, and other related disciplines (e.g., ecology, sociology) to begin the process of acquiring and building evidence to create active community environments. Guided by Urie Bronfenbrenner's socio-ecological framework[159] that focuses on the interaction between individuals and their physical and sociocultural contexts, the present study uses mixed methodology to create linkages in pre-established, discipline-specific conceptual frameworks between public health and urban planning. This is especially important for LMICs like India, where it is crucial to examine factors in the community and BE that promote healthy behaviors.

3.1 Socio-Ecological Framework

Ecological theoretical frameworks address relationships of physical and social environments and human behavior. Such frameworks are the backbone of BE-PA research.[18] They serve as the key organizing frameworks for the public health research testing associations of BE elements with PA. The frameworks also stand behind the environmental and policy interventions designed to change the environment in ways that will facilitate engagement in PA. As with other areas of public health research, BE-PA studies are not typically intended or designed to test and build theory. While some social scientists consider ecological frameworks too broad to be directly

testable, BE-PA researchers do draw from such frameworks and apply multilevel study design and analysis methods to test for behavior-environment relationships.

Bronfenbrenner describes the ecological environment as a nested set of social structures. The structures include:

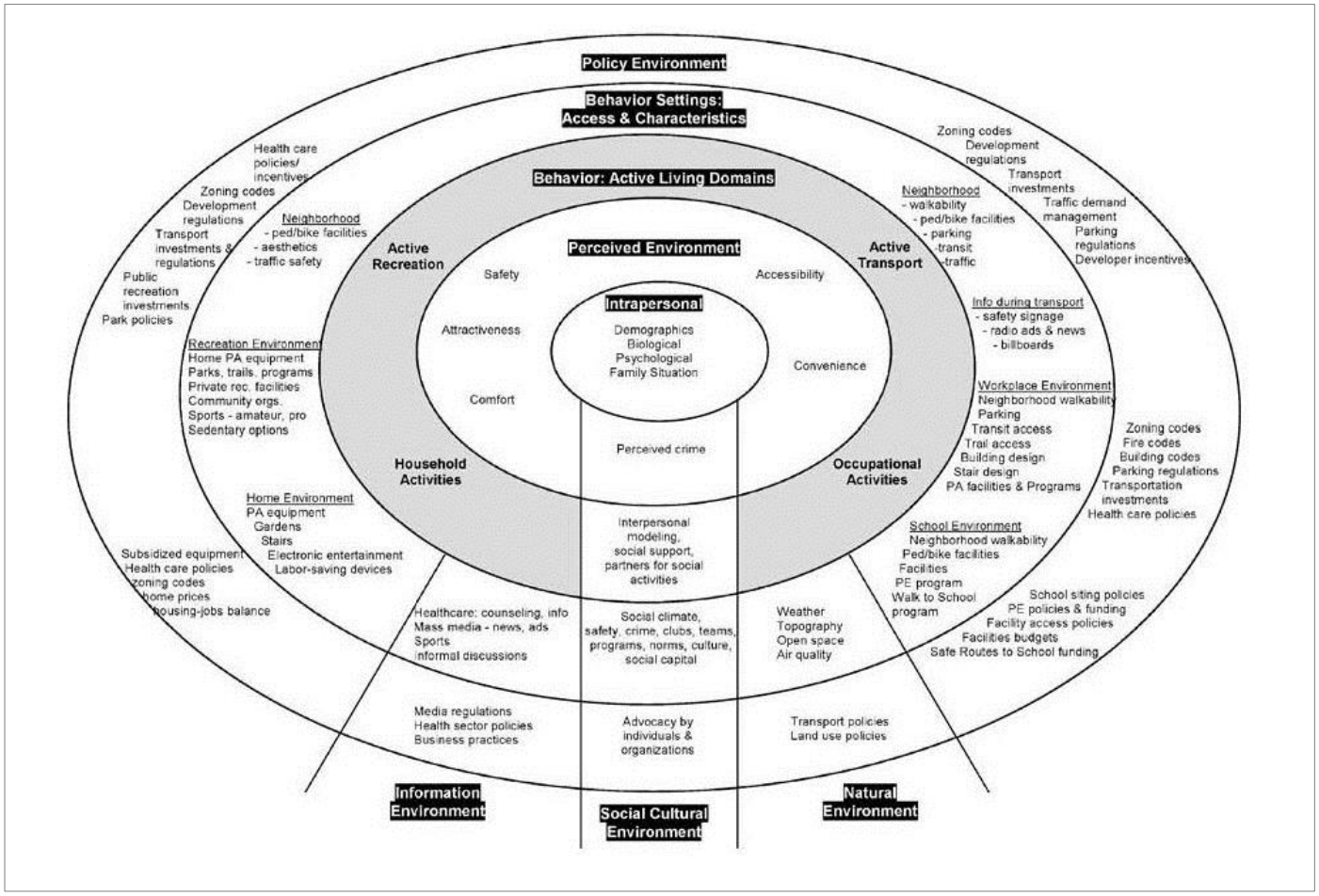
1. A microsystem of relationships between the developing person and the setting, which he defines as the immediate place (school, workplace, home), place-specific activities, physical features, other people (and their characteristics), and particular roles;
2. A mesosytem of interrelationships among major settings;
3. An exosystem of formal and informal social structures that do not contain but do influence the individual, including neighborhoods, government agencies, mass media, communication, transportation, and informal social networks; and
4. A macrosystem of larger political, social, education, legal, and economic systems of a social or ethnic group that shares belief systems, resources, lifestyles, and opportunities

In the microsystem, there is reciprocity in the interpersonal relations, meaning that the actions of one person affect the others. There is also reciprocity in that the developing person changes the immediate settings. Because an individual has different roles in different settings, Bronfenbrenner states it is therefore important to consider the influences of the multiple settings when trying to understand behavior and development. He also emphasizes the importance of the perceived environment over that of the objective environment. While activity takes place in the immediate surroundings within the microsystem, the activities, roles, and interpersonal relations are influenced by the larger social structure surroundings.

3.2 Active Living Framework

Sallis and colleagues (2006) developed a multilevel model was developed to illustrate the roles numerous disciplines can play in research on active living. Figure 1 is an ecological model built around four domains of active living with multiple levels of influences specific to each domain. This model builds on previous ecological models of PA.[26, 147, 155, 160] Broad categories of intrapersonal variables are shown at the center to represent the individual. Psychosocial theories could be used to provide more specificity for this level. Individuals' perceptions of environments are distinguished from more objective aspects of environments, and both are likely to be important influences.

Figure 1. Ecological model of the four domains of active living proposed by Sallis et al. (2006).



Behavior represents the interaction of the person and the environment, with the domains of active living shown at this boundary. The four active living domains of recreation, transport, occupation, and household are consistent with contemporary concepts and are useful for identifying the variety of environments and policies that may influence active living.[26] The PA domains are likely affected by distinct policies and environments. The imperative to consider domains separately is driven in part by different trends by domain over time.[161, 162] The behavioral level is highlighted because this is the outcome of interest.

Behavior settings are the places where PA may occur, and it is useful to consider both access to settings and their specific characteristics. For each active living domain, key behavior settings are listed with illustrative components or characteristics. There are commonalities and differences of relevant environmental factors across active living domains. For example, walkability of neighborhoods refers to the ability to walk to nearby destinations such as shops. This characteristic is relevant for active transport and for walking around workplaces, but probably not relevant for active recreation. Trail systems that link homes and workplaces would be relevant for recreational, transport, and work-related PA. Some influences listed could be expanded greatly. For example, many types of community organizations, such as churches, social service agencies, sports clubs, and child care centers, could provide places, programs, and policies that are relevant to active recreation.

The policy environment can influence active living through a variety of mechanisms, such as the built environment, incentives, and programs. Some policy realms, particularly zoning, development, land use, and transportation regulations, may affect several active living domains. Other policies are domain-specific, such as budgets for public recreation facilities and traffic

demand management policies meant to encourage use of public transit in the commute to work. Health care policies that provide incentives or counseling for PA are relevant to all domains.

The interpersonal environment has been conceptualized in different ways by different authors.[26, 147, 156] In Figure 1, social and cultural environment variables are shown as cutting across the other levels. Family structure can be seen as a demographic variable; modeling and social support are behaviors; social climate, crime, programs, and culture vary by behavior settings; and advocacy by individuals and organizations contributes to policy change.

Natural environment variables of interest include weather, topography, open space, and air quality, and their influences are not confined to specific behavior settings. Land use policies can affect availability of open space, and transport policies can affect air quality.

Information is present in virtually every behavior setting, and commercial promotion of sedentary behaviors is particularly ubiquitous. The information environment can include counseling in health care settings; news, advertising, and program components of mass media; and sports-related information to promote either active participation or sedentary spectating. Setting-specific information sources can be identified, such as televisions and the internet in homes, printed and electronic notices at work, and promotional materials in fitness facilities. Diverse information is transmitted during transportation, such as signs about pedestrian zones, signs pointing to park access, dazzling arrays of commercial signs, an occasional billboard promoting healthful behaviors, and radio broadcasts that inform about exercise events or advertise cars.

Figure 1 communicates complexity about the hypothesized influences on active living and implies that creating significant changes will be difficult and time consuming. Multilevel intervention strategies need to be informed by research. Many of the proposed influences on PA

have not been tested, so the model lays out an ambitious research agenda that will require the combined efforts of investigators from a variety of disciplines. In the following sections, the concepts, methods, and findings from relatd fields engaged in active living research are summarized to illustrate what each field can contribute to transdisciplinary research on active living.

3.3 Urban Design Theories

Urban planning movements dating back to the 1900s aimed at providing citizens with healthier environments. Planning concepts such as the Garden City movement[163] and the Neighborhood Unit[164] specifically aimed at accommodating growing urban populations in self-contained residential neighborhoods within walkable distance to services such as playgrounds, elementary schools, community centers, and additional amenities linked by rail transit. Both concepts viewed vehicular traffic as a dangerous obstacle to pedestrian safety.

3.4 Sociological Approaches

Sociological approaches have established that streets are safer when more people are on them and the steady presence of people in an area encourages walking behavior. Sociologist Jane Jacobs argued the need for a number of effective "eyes" upon a city's streets that come from stores and public places such as bars and restaurants as well as street vendors sprinkled along the sidewalks.[165]

3.5 Criminology

In the fields of criminology and social disorganization, three major theories have focused on physical and social features of neighborhood environments; Newman's Theory of Defensible Space[166], Perkins and Taylor's Theory of Environmental Incivilities[167], and the broken windows theory.[168] These theories have asserted that the overt presence of certain environmental cues in

neighborhood areas (e.g., broken windows, poor street repair, graffiti, litter, and pornographic signage) convey a sense of disorder to occupants. These conditions make a neighborhood appear unsafe, decreasing residents' inclination to use sidewalks, thus impeding walking behavior in their neighborhood.[167]

Using a deductive approach to the theories discussed above, we infer that people are active where they feel safe (pedestrian safety), where there are other people ("eyes on the street"/ sociability), and where there are a variety of destinations (mixed land use).

Chapter 4: Methods

Consistent findings have emerged that supportive BE features are related to PA.[27, 144, 169] A majority of these findings are from the developed countries of North America, Australia, and Europe, and may not generalize to other parts of the world. Questions remain about the applicability of surveys constructed in developed countries to the local contexts in LMICs like India. To address this problem, there have been recent calls for investigators to collaborate on a regional basis to adapt BE measures that are tailored to the LMIC contexts.[45, 46]

The Neighborhood Environment Walkability Scale (NEWS) is the most frequently used questionnaire for assessing perceived attributes of the neighborhood environment for PA worldwide.[35, 55, 170] The International Physical Activity and Environment Network (IPEN) has used NEWS as an instrument to evaluate cross-country analyses of BE and PA relationships.[171] It is a reliable and valid instrument that has been tested internationally and translated into many languages.[35, 170, 172-174] However, the NEWS was developed in the US, and its applicability to other countries may be limited due to differences in culture and environmental features.[57, 58] A primary aim of this study was to systematically adapt the NEWS for BE assessments in India.

4.1 Overview of Research Design and Data Collection Phases

This study employed a non-experimental design with a mixed methods approach for data collection. A combination of qualitative (in-depth interviews, N=21) and quantitative (in-person surveys; N=370) methods were used to collect data from a random sample of adults in 12 wards in Chennai, India. A ward is a subdivision of a local administrative zone in Indian cities, typically used for electoral purposes (equivalent to US census tracts or precincts). Detailed sampling and recruitment strategy is described in Section 3.3. Data collection occurred in the following key phases:

4.1.1 Phase I—Development, Cultural Adaptation, and Translation of NEWS

The survey instrument for this phase was adapted from the Neighborhood Environment Walkability Scale (NEWS) that has been used widely by the International Physical Activity and Environment Network.[35, 170, 172, 175] The NEWS is a self-reported survey instrument to assess BE characteristics relevant for PA. This scale was developed in the US in 2002, and has been successfully implemented in developing countries in Asia (China[57], Japan[176]), Africa (Nigeria[46, 177]) and South America (Brazil[174]) in recent years. This project is the first of its kind to adapt NEWS for India. Initial, qualitative data collection for this phase was conducted between August-December 2013. Data analysis, adaptation, and translation of NEWS was completed by December 2014.

4.1.2 Phase II— Pilot Testing and Cognitive Response Testing

The adapted NEWS-India was interviewer administered to at least 10 adults for cognitive response testing. Cognitive response testing is routinely used to refine questionnaires to enhance the quality of data collected.[178, 179]

4.1.3 Phase III—Survey Administration and Psychometric Testing

The adapted NEWS-India, leisure and travel modules of the International Physical Activity Questionnaire-Long Form (IPAQ-LF[180]), and questions on sedentary behavior from the IPAQ-Short Form 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 previously validated for Indian contexts.[181, 182] Participants were asked to self-report height and weight. The objective of this phase was to understand relationships between the BE and PA.

Reliability and validity (psychometric/measurement properties) testing of NEWS-India was also conducted.

4.1.4 Phase IV— Dissemination of Findings

Findings from this study are being disseminated to the local community, policy makers, public health practitioners, and urban planners in India through op-ed articles in newspapers and development of policy briefs. The study investigator's previously established partnerships with community agencies in Chennai and across other Indian cities are facilitating this process. Detailed description of the study site, sampling, recruitment, and data collection procedures are discussed in the following sections.

4.2 Study Setting

This study recruited a diverse sample of participants from the metropolitan area (164.48 sq. miles) of the city of Chennai, India (Figure 2). Chennai is the capital city of the state of Tamil Nadu, a major commercial and industrial hub in southern India.[183, 184] It is the fourth most populous city (8.9 million residents) in India and the 31st most populous city in the world.[59] The reasons for selecting Chennai were multi-fold: (1) Unlike the three most populated Indian cities (New Delhi, Mumbai, Kolkata) which have older and established transport infrastructures (bus rapid transit or BRT, light rail networks), Chennai is currently undergoing changes in transport systems;[121, 185] (2) Chennai has seen a 24-fold increase in motorized vehicles since 2005 and private automobiles now constitute 55% of daily all-person trips.[121, 186] The percentage of residents commuting by bus (33%), walking (26%), and bicycling (19%) in 2005 have each reduced to less than 10%;[121] (3) Chennai has the lowest walkability index (i.e., least walkable) compared to other cities, with pedestrians marginalized and at the bottom of the traffic food chain;[187] (4) Within India, the state of Tamil Nadu is the most urbanized state with 48.4 percent

of the population living in urban areas[188] and the highest number of diabetic cases, a majority of them being reported in the city of Chennai.[189] All of these reasons make Chennai an ideal setting for this research.

For administrative purposes, the Chennai metropolitan area is divided into 155 smaller subdivisions called wards (Figure 3). Wards are the smallest geographic areas for which the Census Bureau of India publishes demographic information. Due to the lack of consensus on what constitutes a neighborhood,[190] wards were used as the primary definition and unit for sampling purposes.

Participants from diverse ethnic and religious backgrounds were recruited based on the sampling strategy (Section 3.3). The study investigator (D. Adlakha) of this study is a citizen of India, has lived in Chennai for 25 years previously, conducted preliminary field research in India, and established contacts with national agencies (Public Health Foundation of India, New Delhi; EMBARQ-India, Mumbai), local Chennai city departments (Chennai Metropolitan Development Authority, Chennai Traffic Police, Commissioner of Police, Municipal Corporation of Chennai, etc.), and community organizations such as International Transport and Development Programme (ITDP), Transparent Chennai, and Chennai City Connect. Affiliations with these partners and agencies informed and facilitated participant recruitment and data collection.

Figure 2. Map showing location of Chennai, India.

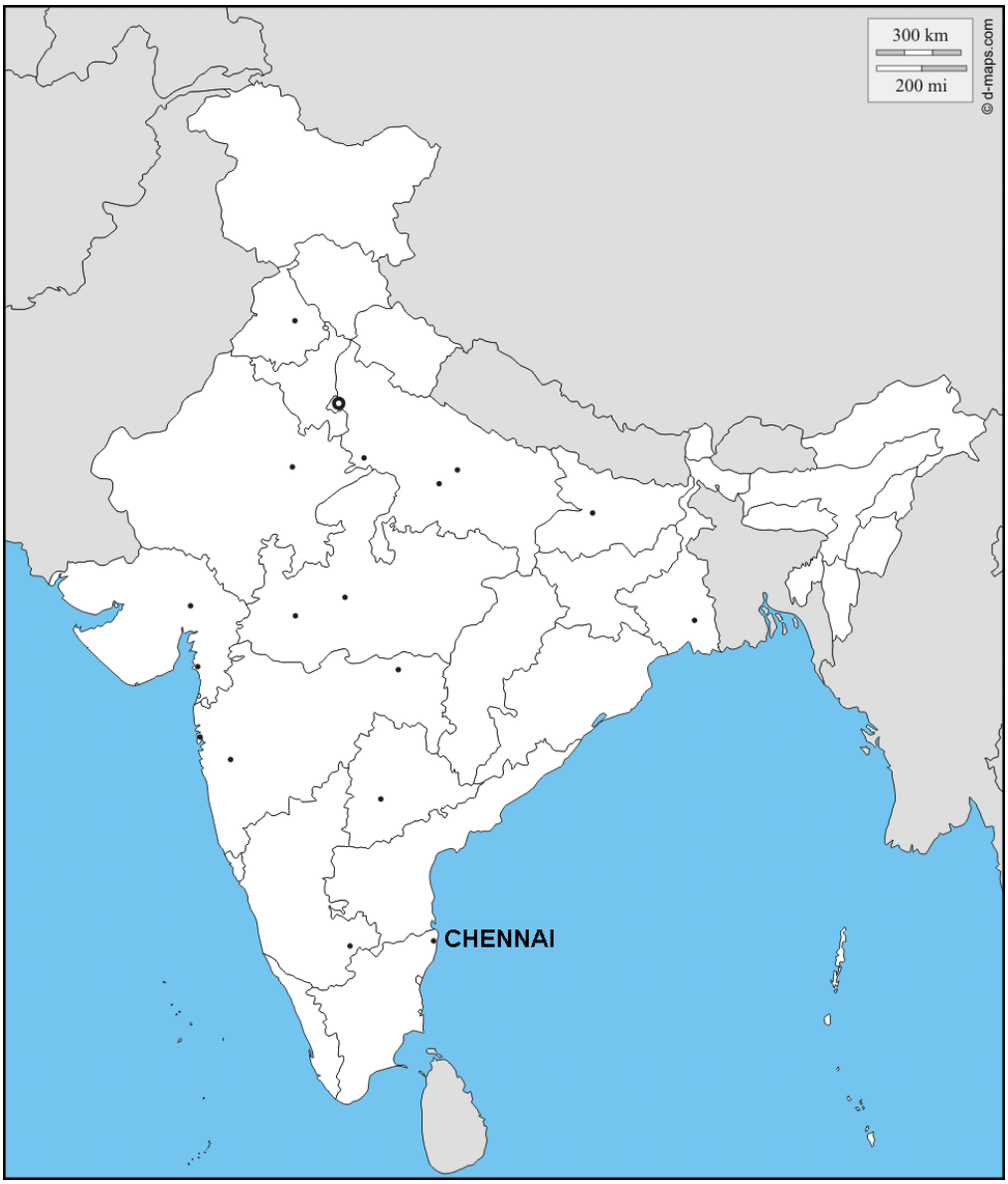
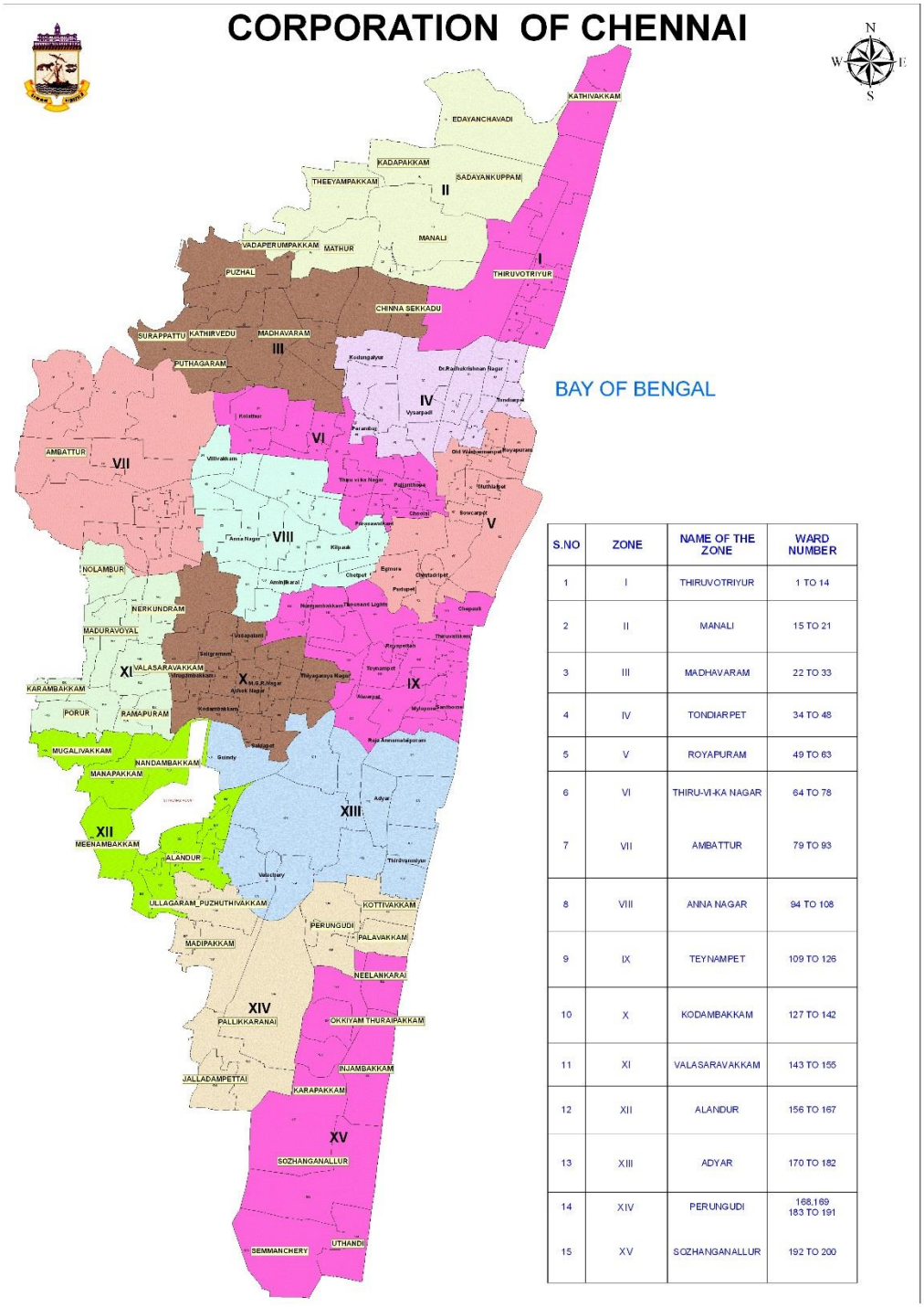


Figure 3. Map of Chennai wards (N=155).



S.NO	ZONE	NAME OF THE ZONE	WARD NUMBER
1	I	THIRUVOTRIYUR	1 TO 14
2	II	MANALI	15 TO 21
3	III	MADHAVARAM	22 TO 33
4	IV	TONDIARPET	34 TO 48
5	V	ROYAPURAM	49 TO 63
6	VI	THIRU-VI-KA NAGAR	64 TO 78
7	VII	AMBATTUR	79 TO 93
8	VIII	ANNA NAGAR	94 TO 108
9	IX	TEYNAMPET	109 TO 126
10	X	KODAMBAKKAM	127 TO 142
11	XI	VALASARAVAKKAM	143 TO 155
12	XII	ALANDUR	156 TO 167
13	XIII	ADYAR	170 TO 182
14	XIV	PERUNGUDI	168,169 183 TO 191
15	XV	SOZHANGANALLUR	192 TO 200

4.3 Sampling and Recruitment

Phase-wise sampling strategy is described below. All procedures were approved by the Institutional Review Board (IRB) of Washington University in St. Louis.

4.3.1 Phase I—Development, Cultural Adaptation, and Translation of NEWS

Local residents (N=14) and key informants (N=7) were recruited using a purposive sampling technique across the Chennai metropolitan area. Purposive sampling has been more effective in the instrument development and adaptation stage and recommended by researchers who have conducted similar studies of this nature in LMIC contexts.[35, 46, 191] Inclusion and exclusion criteria for local residents and key informants were based on IPEN protocol for NEWS adaptation and studies conducted in Nigeria[46], Brazil[115], and China[57].

The study investigator identified a small pool of local residents from formerly established relationships with neighborhood associations, resident welfare associations, and local contacts. In order to ensure selection of a diverse sample, effort was made to recruit residents from different neighborhoods across the city. Eligibility criteria for local residents included: (i) current residents of Chennai metropolitan area; (ii) residents of the Chennai metropolitan area for at least 6 months; (iii) 18-65 years of age; (iv) being able and willing to answer questions in English or Tamil, which is the official language in the study region; (v) not having any disability that prevented independent walking; and (vi) no visible signs of cognitive impairment.

Key informants for this study were chosen on the basis of their interest and related work in local city planning, transportation engineering, walkability, PA, and obesity or diabetes-related research. A multidisciplinary group of seven key informants including but not limited to local city planners, transportation engineers, park and recreation professionals, geographers, and public health scientists were developed from the PI's established contacts. Eligibility criteria for

local experts included: (i) current residents of Chennai metropolitan area; (ii) 18-65 years of age; (iii) ability to speak English or Tamil; (iv) interest in BE and public health issues.

Exclusion criteria for participants were: (i) presence of a medical condition that interfered with the ability to walk; (ii) unsuitable appearance (drunkenness, drug addiction, illegal possession of weapons). Local residents and key informants were excluded from the interviewing sample if they were less than 18 years of age and/or did not consent to being interviewed or audio-recorded.

A list of potential residents and key informants was developed using the above-stated criteria. From this list, participants were contacted either in-person, via telephone or email and asked about their interest and eligibility to participate. All participants that were contacted consented to being interviewed. A convenient time, date, and location for the interview was set for the consenting participants. Research information sheets and interview questions were emailed to participants two days prior to the scheduled interview. Each interview lasted 30-40 minutes and was audio-recorded following privacy and confidentiality procedures outlined in Section B8 (Protection of Human Subjects, pp. 20-21).

Data from interviews were analyzed and a summary report of findings was sent to all participants post analysis. This phase of the study employed a grounded theory approach to support the number of participants. A situation of theoretical saturation was attained where no new categories or properties emerge from the gathering of further data. Based on previous key informant research, 10-15 interviews were expected to provide in-depth information and saturation on emergent themes and issues. Emerging themes from the interviews were discussed with an international panel of IPEN experts including developers of the original NEWS-Adult (Jim Sallis, Kelli Cain, Carrie Geremia, Terry Conway at the University of California, San

Diego, and Rodrigo Reis at Pontifícia Universidade Católica do Paraná, Curitiba, Brazil). Feedback from this panel was used to inform the modification of the NEWS-India as discussed in Section 3.5.2.

The consensus version of NEWS-India developed in this step was translated into Tamil, which is the official language of the state of Tamil Nadu and predominantly spoken in the study region. A knowledgeable bilingual person conducted the translation using terms and concepts that were understood by people residing in Chennai. These translations were reviewed by a group of bilingual people that are similar to the intended users, i.e., residents of Chennai from a wide range of education levels and income groups. The group ensured that the Tamil translation of NEWS was acceptable to monolingual people. Two bilingual persons that were not familiar with the project and representative of eventual study participants (e.g., low-SES, not highly educated) translated the new Tamil version of NEWS-India back into English (back translation). The back-translation was not required to produce the exact original wording. A group of bilingual people reviewed the back-translation and decided on the final translated version of NEWS-India. This process ensured that the meanings of the two versions were comparable. To assess the comparability of item wording, response options, and number of items, the study investigator provided back translations of surveys to two independent raters who were experts in the area (J. Sallis, UCSD; R. Reis, PUCPR).

4.3.2 Phase II— Pilot Testing and Cognitive Response Testing

Cognitive response testing or cognitive interviewing is routinely used to refine questionnaires to enhance the quality of data collected.[178, 179] It is a field research method used primarily in pre-testing survey instruments developed in collaboration by psychologists and survey researchers. It

allows survey researchers to collect verbal information regarding survey responses and is used in evaluating whether the question is measuring the construct the researcher intends.

The adapted NEWS-India was pretested on a minimum of 10 non-professional adults who were able to walk without assistance and could communicate verbally, with no diagnosis of cognitive impairment, and who were residents in the participating neighborhoods during the past six months. Participants for cognitive testing were selected from neighborhood areas that vary in socioeconomic status (SES; high/low income) and walkability (high/low walkable). The study investigator conducted all interviews in this phase. Participants were encouraged to verbalize their thoughts while responding to the survey questions. This method reduced the possibility of the interviewer introducing any bias into the participants' answers. The data collected was then used to modify problematic questions in NEWS-India before fielding the survey instrument to the full sample. Detailed ward-level sampling strategy is discussed in section 3.3.3 below.

4.3.3 Phase III—Survey Administration and Psychometric Testing

This phase of the study adopted a stratified two-stage cluster sampling strategy. Study participants were selected from neighborhoods chosen to maximize the 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.[172, 192] 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, high-walkable/low-SES, low-walkable/high-SES, and low-walkable/low-SES.

The sampling protocol used in this study is based on the recommendations of IPEN studies. A major goal of IPEN is to represent the worldwide variation in BEs. Previous IPEN studies of this

nature have used GIS-based walkability indices to operationalize walkability.[35] To stratify neighborhoods by SES, IPEN studies have used median household income obtained from appropriate government ministries, departments or agencies.[35, 46] Due to the lack of ward-level GIS and household income data for the city of Chennai, Walk Score[**] was used to classify wards based on walkability and cost of rental units per square foot to define ward-level SES. Walk Score is a large-scale, public access walkability index that assigns a numerical walkability score to any address.[193]

Neighborhoods (wards) were divided into ten equal groups (deciles) based on their walkability and SES levels. Neighborhoods in deciles 1, 2, 9, 10 were omitted to avoid outliers. Neighborhoods in deciles 5 and 6 were excluded to create separation between the categories. Neighborhoods in deciles 3, 4 (low walkability) and 7, 8 (high walkability) were selected for potential participant recruitment. Neighborhoods were also divided into deciles by SES and the wards in deciles 3, 4 (low-income) and 7, 8 (high income) were selected for participant recruitment. Neighborhoods in lowest and highest income deciles (1, 10) were excluded to avoid outliers; neighborhoods in deciles 5 and 6 were excluded to create separation between the categories.

Participants were recruited from identified neighborhoods using a purposive sampling technique. The research team formerly established relationships with city government departments (Chennai Metropolitan Development Authority, Chennai Traffic Police, and Commissioner of Police),

[**] Walk Score measures the walkability of any address using a patented system. For each address, Walk Score analyzes hundreds of walking routes to nearby amenities. Points are awarded based on the distance to amenities in each category. Amenities within a 5 minute walk (.25 miles) are given maximum points. A decay function is used to give points to more distant amenities, with no points given after a 30 minute walk. Walk Score also measures pedestrian friendliness by analyzing population density and road metrics such as block length and intersection density. Data sources include Google, Education.com, Open Street Map, the U.S. Census, Localeze, and places added by the Walk Score user community.

non-profit organizations (Chennai City Connect, Transparent Chennai, Institute for Transportation and Development Policy), neighborhood associations, resident welfare groups, and other local community organizations to assist in creating awareness about the study in the neighborhood and facilitating the recruitment process. These relationships were used to establish contact with a small pool of residents in selected neighborhoods. These residents, through their social networks, suggested other residents who were interested in participating in the study. Participants were contacted either in-person, via telephone or email, with up to 6 contact attempts to assess study interest and eligibility. Inclusion and exclusion criteria for participants were based on IPEN protocol and studies conducted in Nigeria,[46] Brazil,[115] and China.[57] Eligibility criteria for local residents 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, which is the 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. Data collection occurred between December 2014 and April 2015.

Sample size was determined using 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.[46, 194] It was determined that 73 participants from each of the four neighborhood quadrants— high-walkable/high-SES, high-walkable/low-SES, low-walkable/high-SES, and low-walkable/low-SES—were needed to detect a moderate-to-large effect size with more than 80% power.[195]

Recruitment continued until approximately 75 individuals from each neighborhood had completed the surveys.

The study investigator made initial contact with participants to provide introductory information about the study, explain study procedures, and obtain verbal consent. Participants were given the choice of completing the surveys in English or Tamil. The study investigator hired and trained bilingual Research Assistants (RAs) for survey administration to eligible and interested participants in Chennai. Prior to allowing an RA to collect data, Letters of Agreement approved by Washington University in St. Louis were obtained. Qualifications for RAs included fluency in English and Tamil, and the ability to understand and adhere to ethical principles of research conduct and confidentiality per Washington University's Institutional Review Board (IRB) guidelines.

The study investigator developed standard answers to common questions from respondents as described in the IPEN protocol for cultural adaptation of NEWS and IPAQ-LF. This information was compiled in a manual and an interview protocol was developed. The protocol was used to train RAs to deal with situations in the field. For example, RAs were trained to use visual show cards to provide culturally appropriate examples indicating the intensity of moderate and vigorous physical activities (e.g., carrying heavy loads=vigorous, playing tennis, household chores like cooking, cleaning, gardening=moderate, etc.). Training protocol included instruction on how to gain participant co-operation without coercion and respond to situations when participants sought clarification and explanation of certain survey terms or questions. The study investigator led observation of mock interviews before going into the field to certify RAs. Training also included study investigator led supervision of interviews at the start of the study to ensure continued adherence to protocol.

Trained RAs administered surveys in-person and in the local language (Tamil), and recorded responses on a hard copy of the survey. Surveys were conducted from December 2014 through April 2015. Surveyed participants were asked if they were willing to be re-assessed a second time, within 2-3 weeks of initial survey administration. Participants that consented for re-testing (N=62, 15% of total sample) were interviewed a second time for the psychometric component (reliability, validity) of this study. There were no significant differences in age, gender, relationship status, religion, and educational qualification between baseline (randomized 62 participants from total sample) and re-test (N=62) participants.

4.4 Survey Instruments and Variables

Phase I of the study used a set of open-ended questions to ask local residents about their attitudes, beliefs, intentions for PA, and perceptions of the BE. Participants were urged to think about their immediate BE when answering these questions. Key informants were asked a set of open-ended questions on BE characteristics, land use policies, transport infrastructure and PA awareness. Key informants were also asked to provide input on the original NEWS.

Phases II and III used the adapted NEWS-India. Phase III used the leisure and transportation modules of the IPAQ-LF[196] to assess domain-specific PA levels. The IPAQ-LF has been widely used in different international contexts for several IPEN studies. It is a reliable and valid instrument, producing repeatable data (Spearman's rho clustered around 0.8) with sufficient internal consistency.[197-199] Culturally appropriate PA examples for India as prescribed by IPEN were substituted.[171] Table 1 provides a phase-wise listing of measures, variables, mode, and time for administration.

Table 1. Phase-wise listing of measures, variables, mode and time of administration.

Phase	Measures	Variables/Constructs	Mode of administration	Time for administration	Sample Size
I	Semi-structured interview questions on perceptions of built environment, attitudes, beliefs, and intentions for physical activity	n/a	Interviewer administered	30-40 minutes	21
II Cognitive response testing	Adapted version of Neighborhood Environment Walkability Scale (NEWS-India)	1. Residential density 2. Land use mix-diversity 3. Land use mix-access 4. Street connectivity 5. Infrastructure for walking/bicycling 6. Safety from traffic 7. Safety from crime 8. Aesthetics	Interviewer administered	20-30 minutes	12
III	NEWS -India	Same as above			
	and				
	International Physical Activity Questionnaire-long form (IPAQ-LF): Travel and Leisure domains	1. Moderate-to-Vigorous PA 2. Walking time 3. Sedentary behavior (sitting time)	Interviewer administered	30-40 minutes	370 (baseline) 62 (Re-test)
III	Socio-demographic Questions	age, gender, religion, caste, SES (income and education)	Interviewer administered	10 minutes	370 (baseline)

Table 2. Subscales, sample items, and response options from the Neighborhood Environment Walkability Scale adapted for India (NEWS-India).

Subscale	Response options	Sample Items
Residential density	1 (none) to 5 (all)	How common are independent houses or bungalows in your neighborhood? How common are 1-3 storey flats or apartment buildings in your neighborhood? How common are slums in your neighborhood?
Land use mix–diversity	5 (1-5 minutes) to 1 (>30 minutes)	How long would it take to get from your home to the nearest business or facility listed below if you walked to them? ▪ Supermarket ▪ Fruit or vegetable market ▪ Post office ▪ Bus stop or railway station ▪ Place of worship (e.g., temple, mosque, church, etc.)
Land use mix–access	4-point Likert scale 1 (strongly disagree) to 4 (strongly agree)	I can do most of my shopping at local shops. There are many places to go within easy walking distance of my home. There are major barriers to walking in my neighborhood that make it difficult to walk (e.g., bad roads, poor sidewalks, water logging).
Street connectivity		There are many four-way road junctions in my neighborhood. The streets in my neighborhood do not have many dead-ends. There are walking paths in my neighborhood that connect dead-ends to main roads or streets.
Walking/ bicycling facilities		The footpaths/pavements in my neighborhood are well maintained (paved, even, and not a lot of cracks). There are zebra crossings (crosswalks) and pedestrian signals to help walkers cross busy streets in my neighborhood.
Aesthetics		My neighborhood is generally free from litter/garbage, graffiti, or stagnant water. There are attractive buildings/homes in my neighborhood.
Pedestrian/ traffic safety		There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighborhood. When walking in my neighborhood there are a lot of exhaust fumes (such as from cars, buses).
Safety from crime		There is a high crime rate in my neighborhood. The crime rate in my neighborhood makes it unsafe to go on walks at night.

Note: All environmental scales and items were positively scored, i.e. higher score=more walkable/activity-friendly.

4.5 Data Collection Procedures

4.5.1 Phase I—Development, Cultural Adaptation, and Translation of NEWS

Between August and December 2013, semi-structured interviews were conducted with local residents and key informants. Residents were asked questions on the perception of their neighborhood BE as well as attitudes, beliefs, and intentions for PA**.** Key informants were asked to provide input on the original NEWS questionnaire and to think about environmental factors that are important for both cities and villages in India. Key informants were also instructed to help identify items on the NEWS that are not relevant to local environments in India and to suggest culturally appropriate and equivalent items in the Indian context. The goal was to retain as many original concepts and items as possible, but to express them in ways that are appropriate for the local culture and environment. Most importantly, key informants were asked to suggest inputs on environmental factors that are important for PA in India that are missing on the original NEWS. Key informants were asked to consider both physical BE and social environment. Social environments included presence of others, crime, gang activity, and indicators of social disorder such as graffiti trash, and people begging.

Responses from local residents and experts were used to inform the modification of the NEWS-India. International experts (Jim Sallis, University of California, San Diego; Rodrigo Reis, Pontifícia Universidade Católica do Paraná, Curitiba, Brazil) who were associated with the development of the original NEWS reviewed the adapted version of the NEWS-India. These international experts ensured that the underlying concepts assessed by the NEWS questionnaire were not compromised during the adaptation process.

4.5.2 Phase II—Pilot Testing and Cognitive Response Testing

The adapted NEWS-India was interviewer administered to 10 consenting adults for cognitive response testing. To encourage critical feedback of the NEWS-India, participants were informed that the questionnaire was originally developed in the US to assess attributes of the neighborhood BE that are important for PA in developed countries. Participants were interviewed separately and/or in a focus group, for their understanding of the words in the questionnaire, clarity of each item, and their suggestions for improvement. Participants were asked to verbalize their process of: (i) question comprehension (clarity of words, terms); (ii) information retrieval (response recall time); and (iii) decision making (aspects considered when choosing the response). Participants were also asked if any question made them feel uncomfortable and if any relevant item in the local context was not included in the questionnaire. All participants were encouraged to verbalize their thought process while providing responses to the items. Results from this pilot test were discussed with the international expert panel and subsequently used modify to NEWS-India.

4.5.3 Phase III—Survey Administration and Psychometric Testing

The adapted and final version of NEWS-India and IPAQ-LF were interviewer administered to consenting participants (N=370). NEWS-India was administered for a second time to consenting participants (N=62) with a gap of 2-3 weeks between successive administrations.

4.6 Human Subjects Protection

The study was granted exempt status as per Washington University's Human Research Protection Office. All study participants and data collected was protected according to HIPAA privacy and security regulations.[200] Publications from this study will also protect the identity of all research participants per HIPAA regulations. The study did not require any approvals from

authorities in India since the study investigator was affiliated with and funded by Washington University in St. Louis.

4.6.1 Informed Consent Procedures

Participants were informed about study objectives and confidentiality procedures prior to data collection. The consent form was reviewed verbally with each participant before the survey and all participants provided verbal consent in advance of participation. In order to account for study participants who were unable to read and/or write, verbal consent was applicable for this study. The study investigator followed the steps below to obtain verbal consent:

Step 1: The study investigator explained the study to the participant verbally, providing all pertinent information (purpose, procedures, risks, benefits, alternatives to participation, etc.), and allowed the participant ample opportunity to ask questions. Participants were also informed that their participation in the survey is voluntary, that they may decline to participate in the survey at any time or leave the process incomplete, skip or decline to answer a question when feeling uncomfortable.

Step 2: Following the verbal explanation, participants were provided with a study information sheet (written summary per IRB regulations) to ensure participants could make an informed decision about their participation and information they choose to share. Participants were given sufficient time to evaluate the procedures, risks, potential benefits, potential alternatives, and will be allowed to consider whether or not to participate in the research.

Step 3: After allowing the participant time to read the study information sheet, the study investigator answered any additional questions the participant had and obtained verbal agreement to participate in the research. No incentives were provided to participants following IRB approval.

4.6.2 Privacy and Confidentiality

All participants were treated in a professional manner and with respect for their confidentiality. The study investigator trained all RAs in research ethics and confidentiality procedures. No sensitive information was gathered during the surveys. To ensure confidentiality, research participants were assigned a code number for de-identification purposes and any personal identifying information was removed from the data. Participant names or any form of personal or identifying information was removed from records that contain data. The dataset was de-identified for analysis and future archiving. Data security measures such as locked filing cabinets, password-protected databases and computers, and encrypted network drives were employed. To minimize risks while in India, all hard copy study materials (surveys, field notes, etc.) were securely stored with the study investigator in a locked container. When survey responses were transferred to an electronic database in India, they were stored on a password-protected file on the study investigator's research laptop, and on an encrypted flash drive and secure Washington University server (via remote connection) as a backup. While traveling from India to the US, study materials were transported under the supervision of the study investigator. De-identified electronic files were password-protected and stored on a secure, encrypted Washington University server.

4.7 Data Analysis

4.7.1 Qualitative Analysis

Inductive and thematic analysis was conducted across the interview transcripts, using a framework approach to classify data according to key themes and emergent categories.[201] Once all transcription was complete, the transcripts were read by two research members. Themes were recorded and shared with the research team to develop a consistent coding scheme to be used

within NVivo 10.[202-204] One team member present at the interview and one not present then coded each transcript using the developed coding scheme.

There were five broad categories of original interest, as structured in the semi-structured interview questions: neighborhood environment characteristics including pedestrian infrastructure, patterns of commuting, constraints to walking/bicycling and other types of PA, desired changes in infrastructure for the benefit of physical, psychological, and social well-being, and role of city-community partnerships in neighborhood planning and maintenance. As the nodes for coding the data were identified, several distinct patterns were recognized. Constant comparison was used to further investigate these patterns across social ecological systems in a matrix form similar to that used by Zayas and colleagues (2010).

4.7.2 Quantitative Analysis

Quantitative analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 20.[205]

Assessment of Reliability

The reliability of the items of the adapted NEWS-India was assessed in two ways: the agreement of scores using the calculation of the kappa statistic for each item and one-way model single-measure intraclass correlation coefficients (ICC). Portney and Watkins suggest that when the unit of measurement is on a categorical scale, reliability can be assessed using a measure of agreement.[206] A simple index of agreement is the proportion of occasions that raters agree on scores, although this measure is limited as it does not take into account the level of agreement that could have occurred by chance. The kappa statistic overcomes this limitation by providing a chance-corrected measure of agreement.

To evaluate the test-retest reliability of the adapted NEWS-India, one-way model single-measure intraclass correlation coefficients (ICC) were calculated to test individual items. To test NEWS scale scores computed from multiple items, the single-measure ICC was also computed. ICC represents the proportion of total variance in a set of values that is attributable to between-subjects variability, with the remaining proportion attributable to error. ICC estimates >0.75 were considered as good reliability scores, between 0.50 and 0.75 as moderate reliability and <0.50 as poor reliability.[207]

Descriptive Statistics

Descriptive statistics are presented for the socio-demographic characteristics of all participants. Body mass index (BMI) was calculated as body weight divided by the square of height (kg/m^2). The World Health Organization principal cutoff points for BMI were used to create the categories: underweight (< 18.5 kg/m^2), normal weight (18.5–24.99 kg/m^2), overweight (25–24.99 kg/m^2), and obese ($\geq$30 kg/m^2).[13] Differences in socio-demographic characteristics of the sample between neighborhood quadrants were examined with one-way Analysis of Variance (ANOVA) tests for continuous variables and with chi-square tests for nominal variables. 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). Scoring procedures followed the NEWS-Adult scoring scheme recommended by the IPEN study protocol. [52, 53, 139] All NEWS-India items were positively scored to ensure that a higher score denotes a more walkable/activity-friendly neighborhood. The Residential Density (RD) subscale was calculated as a weighted score of 7 items [RD=RD1+(10*RD2)+(25*RD3)+(50*RD4)+(75*RD5)+(100*RD6)+(125*RD7)]. These weighting values are based on approximate density of households per unit area relative to a

single-family detached residence as prescribed in the IPEN protocol for NEWS scoring.[52, 53, 139] All other subscale scores were calculated as mean of Likert-type scale item responses. An aggregate NEWS-India score was calculated using Likert-type scale responses from all items except the weighted residential density subscale items.

Logistic Regression Modeling

Dichotomous PA outcomes ≥ 150 minutes per week were computed for the following PA types: walking for travel, bicycling for travel, total travel PA, leisure-time walking, leisure-time Moderate-To-Vigorous Physical Activity (MVPA), total leisure PA, total MVPA, and total PA. The cut-off value of ≥ 150 minutes per week are based on global recommendations on PA for health among adults established by the WHO.[208] It is recommended that adults aged 18–64 should do at least 150 minutes of moderate-intensity aerobic PA throughout the week or at least 75 minutes of vigorous-intensity aerobic PA throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity.

The BE predictor variables were also dichotomized. Residential density was dichotomized into low (weighted mean ≤ 545) and high (weighted mean > 545) densities using the mid-point of the range of residential density values from the sample. Land use mix-diversity was dichotomized into ≤ 10 minutes walking distance or ≥ 10 minutes. A distance that can be comfortably walked in 5-10 minutes is the recommended distance most people are willing to walk to public transit and other neighborhood destinations.[209, 210] This walk time corresponds to approximately 1/4 mile to 1/2 mile at the standard walking speed of 3 mph.[211] Four-point Likert-type scale response options for all other subscales (land use mix-access, street connectivity, infrastructure for walking/bicycling, aesthetics, traffic safety, 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 also 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 series of multiple logistic regressions were used to identify BE predictors of meeting WHO-recommended levels (≥ 150 minutes/week) for travel, leisure, and total PA (dichotomous outcomes). A first set of models (Models 1a-1c) estimated unadjusted and adjusted (age, gender as covariates) odds ratios by neighborhood SES (low, high) and the pooled sample. The next set of models (Models 2, 3) estimated adjusted odds ratios for the pooled sample only. Model 2 was adjusted for socio-demographic covariates (age, gender, education). Model 3 was adjusted for age, gender and a design variable (sampled neighborhood quadrants).These covariates were explicitly chosen in order to control for their confounding effects in the logistic regression models. This helped to partial out the effects of socio-demographic variables and neighborhood quadrants in order to assess the main effects of BE variables of interest.

Chapter 5: Results

5.1 Inductive Analysis

In the process of performing the inductive analysis, it became salient that BE barriers and constraints to active commuting and PA behaviors were not only perceived by individuals, but constraints also intersected with social ecological systems. Though some specific constraints were unique to the individual and to the specific neighborhoods, there were mostly shared constraints. In total, themes addressed in the interviews were organized into the social ecological categories: micro, meso, exo, and macro-level factors.[212, 213] Micro-level factors included perceived constraints at the individual level (e.g., overcrowding, lack of maintenance and cleanliness). Meso-level factors influenced PA behaviors in interpersonal specific user groups (e.g., women, older adults) across behavioral settings (e.g., poor pedestrian infrastructure and public transport access, lack of safety from traffic). Exo-level factors equally constrained PA participation by all members of the community (e.g., crime, gender-based violence, loss of sense of community) and macro factors were society-level constraints (e.g. disordered city planning, absence of road safety policies and law enforcement). Examples of socio-ecological factors at these levels are presented in Table 3.

5.1.1 Micro

Several perceived individual-level factors were identified. Residents cited proximity to work/ school and access to diverse destinations as reasons for neighborhood selection. Micro-level constraints were identified as limiting individuals from being physically active and were a common narrative acknowledged in several interviews with residents. For example, lack of maintenance of neighborhood parks and playgrounds constrained the use of these spaces for PA among multiple participants. Individuals spoke of specific barriers and instances of constraints to

PA due to lapses in maintenance and cleanliness in their neighborhoods. Overcrowding, disorderly traffic, and lack of sidewalks were identified as barriers to PA. For example, in reference to sidewalks with gaps and in disrepair, residents [R] said;

R8: "Pavements are dirty, it is not at all good for walking."

R10: "For the pedestrians there is no space in the city. There are no proper pavements in most parts of the city. If there are pavements also, the bikes [motorized] will travel on the pavements. There is no respect for pedestrians in the city."

R10: "I do walk, but it's not a very good experience. The pavements will be dug up and you won't have any place to walk on them. It's such a narrow road and you have buses coming. I don't mind buses but it's crazy the way they drive, so I am really scared to walk."

5.1.2 Meso

Perceived constraints to PA specific to user groups and between behavioral settings were identified. Residents reported rapid development and construction of apartment complexes and increased commercial activity in residential areas, resulting in loss of green cover. Scarcity of road space and insufficient parking spots to accommodate increases in motor vehicle ownership across households were discussed. Lack of pedestrian infrastructure to support walking was highlighted. Several residents expressed concerns about threats to safety from traffic, particularly for women and older adults in their families. One resident said:

R3: "There is practically no sidewalk in any part of the city. People are seen walking on roads. Except for the time I go to the park in the morning, I have to walk on roads. Walking in the park is much safer in the sense you know where you are walking.

Wherever there are sidewalks, they are not worth walking on. And the government has not given importance to sidewalks and cycling. Women and elderly find it difficult."

R12: "They [city government] have dug up the road and the pedestrians, they can't walk. And my dad, his eye sight is very bad, so he is not allowed to go outside after dark because he cannot cross the road. Most of the accidents occur with cyclists and pedestrians. They are very prone to accidents because there is no security."

Residents discussed the desire to engage in everyday PA, but attributed the inability to do so due to non-existent sidewalks, high volumes of unregulated vehicular traffic, and poor enforcement of traffic rules. A few long-term residents recalled walking for errands (e.g., to the grocery store, library, etc.) and engaging in outdoor recreation or leisure PA in local parks and playgrounds in previous years, but reported being increasingly inactive or sedentary for leisure at present (watching TV, playing video games, sleeping, doing household chores, sitting at a desk, etc.). Reasons for this were cited as overcrowding and lack of existing opportunities or places for outdoor leisure-time PA. Residents said:

R2: "Earlier I would go out and walk, I mean, at least three to four times a week to run small errands, to go to the library, to go shopping, but that is not possible at all because the road is very bad due to the metro [metro rail construction] going on. The main road is one-way [one-way traffic] and the traffic volume is too much. It's very difficult to cross the road. And there's no space to walk on the sidewalks where you can walk carefully, so that puts me off and I don't walk at all."

R1: "I used to bicycle to the beach every weekend. But nowadays, because the traffic is so dangerous, I have stopped using my bicycle. I spend my weekends watching TV and

playing games on the computer. Sometimes I play volleyball with my friends on the beach."

Older adults reported going to neighborhood parks the most. However, despite living in streets adjacent to a park, they reported being unable to walk to the park due to increased road traffic volumes. They most commonly drove to the park and then engaged in PA within the PA boundaries.

R2: "There is a park but getting to the park is a 20-minute walk and then you have to brave all the traffic and go to the park. So if the conditions were better I would not mind walking to the park and then having a walk in the park."

5.1.3 Exo

Study participants mentioned a strong sense of community and presence of religious institutions as key reasons for neighborhood selection. One of the participants stated that the primary reason for buying their house was because their neighborhood had a high concentration of people from the ethnic group/ Indian state they belonged to:

R6: "One of the reasons they [parents] bought it [their house] may be like a sense of community because, you know, there are lot of demographics living in Chennai, and they were Malayalees and they had come from Kerala [southern Indian state]. So it sort of grew up like a little "Mallu" [colloquial term for Malayalee-a type of ethnic group in India] colony. All the people around you were sort of neighbours, were Malayalees. Because of that a temple came up. The temple was originally a Kerala temple."

Another participant mentioned that easy access to temples around their home was a key factor for choosing to live in their neighbourhood:

R9: "My parents are extremely spiritual people and there are lots of temples around, so they like to go there."

Several Participants also identified distinct community-level constraints that were consistent across different areas of Chennai where they lived. For example, one of the participants mentioned a lack of any face-to-face contact and feeling disconnected from the neighbors on the street. This has resulted in a loss in the sense of community:

R2: "This used to be a friendly, clean, and quiet neighbourhood. Before we used to walk on the road, stand at least near the gate and wave at each other. Now we don't have any communication with our neighbours."

Participants discussed safety concerns and gender-based violence against women and girls in their neighborhoods, streets, and public spaces. Some female participants mentioned having inferior access to public transport, feeling unsafe when walking alone after dark, and being subject to sexual harassment. The prevalence of these forms of gender-based violence in the exo-level system has resulted in making the public space a restricted area for women and girls, eliminating freedom and the human right to participate in the cultural and social life of the community. One of the participants narrated incidents of women being subject to inappropriate comments while walking on the streets:

R14: "You can't say crime but there are people standing, passing lewd comments."

5.1.4 Macro

At the macro or societal level, participants discussed attitudes and ideologies of the government and community organizations. Residents mentioned that roads were designed to be automobile-dependent, neglecting pedestrians and bicyclists. Key informants were critical of the government policies on transport and pedestrian infrastructure. A common theme across all key informants

was government policies were one-sided by favoring the automobile over pedestrians and bicyclists, resulting in high pedestrian fatalities. Key informants said:

> *KI1: "Till the government doesn't prioritize that pedestrian infrastructure is important and think laterally, road safety will be completely neglected in our city."*
>
> *KI2: "Most of our roads are built only for cars, that's the only demand that is visible for them [government], so many people have been coming up and saying you know, look at pedestrian safety."*
>
> *KI5: "It [road safety] is a very practical difficult issue to go around because the traffic on the road in my opinion in India is a million times worse than any other city in the world. In many ways Indian traffic situation is really really bad, not only because it is overly congested compared to any other city around the world but it is also multi-vehicle, from bikes to say, any concept you try to apply, there is always a loophole. For example, it is very difficult to simulate these things anymore because behaviour of a bike or 'thela gaadi' [hand-drawn cart for transporting goods] and so on, is very different from the behaviour of a car. Bikes squeeze in, about 50-60% of Chennai traffic are bikes, so the way they behave, is completely different from your typical discussion on traffic in say, America, or any other country in the West."*

Participants criticized the haphazard and uncoordinated nature of work across government departments. Residents spoke about a lack of political will among political leaders and no vision when it comes to planning for the future. Several residents of the city believed that decisions taken by local municipal leaders without giving much thought to future prospects were responsible for the haphazard growth in the city. Discussing this lack of foresight, a resident said:

R5: "Building a city is no joke. It is not like "Lego" that you just, you know, put in a few pieces and "Oh the city is there". You need proper foresight."

Several participants discussed the need for greater collaboration among city departments and improved partnerships between the city and neighborhood associations for improvement and maintenance of infrastructure, roads, and pedestrian facilities.

KI5: "All the things we just mentioned requires multiple departments and multiple coordination and multiple capacity."

R2: "If the government, the corporation, if they do things at that [community] level I'm sure the neighborhood will also join hands and see to it that their streets are encroachment free and they'll see to it that they're kept neat and clean. There are neighborhoods where they do have competitions and like the people on their own beautify their sidewalks and they give out prizes for all these things. So these are all the things people can do at the community level. Once they find that things are kept neat and clean, I'm sure they will do their part of it."

Overall, findings from qualitative interviews underscored the importance of a planned and structured BE as a channel to promote healthy and active living.

Table 3. Examples of socio-ecological factors related to the built environment and physical activity in Chennai, India (N=21).

Socio-Ecological Levels	Themes and Quotes
MICRO (e.g., individual, family, peers)	**INDIVIDUAL AND FAMILY FACTORS** *"There's no space to walk on the sidewalks where you can walk carefully so that puts me off and I don't walk at all"[R2]* *"It's just not safe to walk outside, and it has become so bad that my mom said I want a treadmill at home and we bought a treadmill and my mom is walking on that."[R5]* *"We did consider the children's school was nearby and my husband's office was nearby so that was a reason why we considered this [residential neighborhood]."[R2]* *"My parents are extremely spiritual people and there are lots of temples around, so they chose this house. And my dad he is diabetic, so walking is compulsory for him. So the beach is close by and that is why he liked this place."*
MESO (e.g., connections between individual and the environment)	**NEIGHBORHOOD ENVIRONMENT** *"It is basically a concrete jungle."[R1]* *"It [neighbourhood] used to be like a walk in a park, literally. In my neighbourhood before, there were open stretches of land, couple of residential houses, and no apartments. Now, there is hardly like any plot that is available for people to buy."[R5]* *"Every household has at least one car and two bikes [motorized], and there is no place to place to park. There are many flats in Chennai that don't have garages or parking facilities, so people end up parking on the roads. Those parked cars on either side make the roads even narrower to make things worse"[R5]* *"Green cover has come down by 50% since we moved in." [R3]* *"Because of commercial activity, all the old houses are being pulled down and big complexes are coming up and all the trees are being cut down so all the shade is gone. As it is the weather is very hot and humid so it is not really favorable to walk in the hot sun in the afternoon."[R2]* *"When it rains, we don't have a proper sewage system, so the drainage and the sewage all comes out, the dirty water comes out on the roads and people have to travel. Because there are no sidewalks they end up traveling you know, through the muddy and dirty water." [R5]*

PEDESTRIAN INFRASRUCTURE

"There is a lot of unauthorized parking and the sidewalks have too many obstacles like some hawkers and laundry shops and garbage bins. And so it is like obstacle race if you want to walk on the sidewalk you have to keep getting up and down."[R2]

"I have aged during the last 22 years and have a problem with my knees. I just can't keep getting to such a high sidewalk again and getting down again." [R2]

"There is practically no sidewalk in any part of the city. People are seen walking on roads. Except for the time I go to the park in the morning, I have to walk on roads. Walking in the park is much safer in the sense you know where you are walking. Wherever there are sidewalks, they are not worth walking on." [R3]

There are many parts in the city where you will feel unsafe because streets are not lit up properly."[R10]

TRAFFIC SAFETY

"Traffic has increased a lot on the roads and the traffic is not very pedestrian friendly and it's very difficult to walk. And to cross the road you have to like risk your life and cross the road."[R2]

"Motorists and the two-wheeler riders they don't respect it [crosswalks] at all so you have to be very, very careful while crossing the road." [R2]

"If you want to have a nice walk, there is a park but getting to the park is a 20-minute walk and then you have to brave all the traffic and go to the park. So if the conditions were better I would not mind walking to the park and then having a walk in the park".[R2]

"The traffic is chaotic and nobody respects the traffic rules. The motorists they jump signals. Even if it is a one-way street you see people coming the opposite direction. They just don't respect the traffic rules." [R2]

A lot of accidents are happening particularly on this road. I have at least seen some 3-4. In a day we at least have 4 ambulances coming and picking up people on this particular road." [R7]

"I have travelled kilometres to reach my home when it was raining one day because the traffic just would not budge, so we just got off whichever transport we were using, we walked like 10-15 kilometres to reach my house."[R1]

"The roads were built for the number of people that were there say 50 years ago and we are still using the same [roads], and the population has multiplied by say a 100 or 1000 times."[R5]

"I make it a point not to step out of house because of the traffic and dirty roads. I feel I am safe at home than going out." [R8]

	"Crossing the road, I feel sorry for senior citizens and the elderly." [R10]
	PUBLIC TRANSPORT
	"Commuting there is pretty bad with regard to the roads and things especially public transport, there is hardly any transport there. There are no buses at all. Whatever it is, is like a few autos maybe 1 or 2 that commute to that area" [R1]
EXO (e.g., social networks and neighborhood community contexts, local politics and industry, mass media, social services)	**NEIGHBORHOOD COMMUNITY**
	"One of the reasons they [parents] bought it [the house] was a sense of community. All the people around you belonged to the same community."[R6]
	"This used to be a friendly, clean, and quiet neighbourhood. Before we used to walk on the road, stand at least near the gate and wave at each other. Now we don't have any communication with our neighbours. It is so damn dirty and stinky, you don't want to stand outside, so in that process we are losing our identity."[R8]
	"*You can't say crime but there are people standing, passing lewd comments." [R14]*
MACRO (e.g., attitudes and ideologies of culture, customs, and laws)	**POLICY**
	"The road safety policy has never addressed pedestrian necessities." [KI1]
	"Till the government doesn't prioritize that pedestrian infrastructure is important and think laterally, road safety will be completely neglected in our city." [KI1]
	"Most of our roads are built only for cars, that's the only demand that is visible for them [government], so many people have been coming up and saying you know, look at pedestrian safety." [KI2]
	PLANNING
	"Fifty-two percent of city trips are less than 5 kilometres, if you improve pedestrian infrastructure and improve cycle tracks, imagine how much fuel we would save." [KI1]
	"They [city government] wanted a dedicated lane for pedestrians and cyclists, but somehow that plan took a back seat and now they want to build a 50 kilometre elevated expressway again."[KI2]
	"In many ways Indian traffic situation is really really bad, not only because it is overly congested compared to any other city around the world but it is also multi-vehicle, from bikes to say, any concept you try to apply, there is always a loophole. For example, it is very difficult to simulate these things anymore because behaviour of a bike or 'thella gaadi' [hand-drawn cart for transporting goods] and so on, is very different from the behaviour of a car." [KI5]

"Building a city is no joke. It is not like "Lego" that you just, you know, put in a few pieces and "Oh the city is there". You need proper foresight."[R5]

CITY-COMMUNITY PARTNERSHIP

"If the government does things at that [city-community partnership] level, I'm sure the neighborhood will also join hands and see to it that their streets are encroachment free and they'll see to it that they are kept neat and clean. There are neighborhoods where they do have competitions and the people on their own beautify their sidewalks and they give out prizes for all these things." [R2]

"The government has to work hand-in-hand with people." [R5]

They [local community] are not supportive about this whole widening of the pavement. Some of them, they say "Oh, the roads are already choked and by increasing the pavements you are going to choke it further, so where would our vehicles go?" [KI1]

LAW ENFORCEMENT

"Enforcements have to step up, traffic police is grossly understaffed." [KI2]

"Police only concentrate on getting the money out of the people, they are not bothered about regulating the traffic or doing something for the people." [R12]

"They [police] can put a firm hand and first of all on all these unauthorized shops and all the encroachments that have happened on the sidewalks. They have to be removed. Plus the unauthorized parking. I mean, you even find sometimes two-wheelers are parked on the sidewalks. So they have to take care of all these issues and like come down on all these people so that things improve for the general public as such."

Note: R=Resident; KI=Key Informant

5.2 Test-Retest Reliability

Table 4 shows the response frequency and mean score of each item on the first assessment of the adapted NEWS-India and its test-retest reliability scores. The ICCs of the sum scores of each of the eight subscales (residential density, land use mix diversity, land use mix access, street connectivity, infrastructure for walking/bicycling, aesthetics, traffic safety, and safety from crime) ranged from 0.85 to 0.98. All subscale ICCs were higher than 0.75, indicating excellent reliability. ICCs of the individual items ranged from 0.48 to 1.00 with the lowest scores for a particular item of the 'infrastructure and safety for walking and bicycling' subscale. In total, reliability of 80 items was in almost perfect agreement, reliability of 9 items was substantial and reliability of two items was moderate.[207] The moderate reliability scores were probably due to a lack of variance in the answers, as the proportion of agreement for the two items with moderate reliability was generally high (>0.70 for the two items with moderate ICC reliability).

Table 4a. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Residential Density.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)						Test-retest Reliability Scores (N=62)	
	None	A few	Some	Most	All	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Residential Density								**.88**
a) independent houses or bungalows	21.4	13.5	14.3	28.4	22.4	3.17 (1.47)	3.63 (1.09)	.91
b) 1-3 storey flats or apartment buildings	15.4	15.1	20.0	34.1	15.4	3.19 (1.30)	3.79 (1.04)	.88
c) 4-6 storey flats or apartment buildings	49.7	10.0	10.8	19.5	10.0	2.30 (1.48)	2.79 (1.57)	.96
d) 7-12 storey flats or apartment buildings	86.2	5.9	4.6	1.4	1.9	1.27 (0.77)	1.21 (0.83)	.83
e) 13-20 storey flats or apartment buildings	93.5	3.0	1.6	0.5	1.4	1.13 (0.59)	1.10 (0.56)	.95
f) over 20 storey flats or apartment buildings	96.5	1.9	0.8	0.0	0.5	1.05 (0.37)	1.03 (0.18)	1.00
g) presence of slums	51.6	14.6	8.4	6.2	18.9	2.25 (1.58)	2.42 (1.50)	.88

Table 4b. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Land Use Mix-Diversity.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)						Test-retest Reliability Scores (N=62)	
	1-5 min	6-10 min	11-20 min	21-30 min	≥ 31 min	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Distance to facilities (Land Use Mix-Diversity)								**.96**
a) Provision store	3.5	4.6	11.4	25.9	54.6	4.24 (1.05)	4.53 (0.65)	.78
b) Supermarket	24.3	7.6	10.8	28.4	28.9	3.30 (1.55)	3.82 (1.34)	.97
c) Government ration shop	27.6	11.9	15.7	25.7	19.2	2.97 (1.50)	1.97 (1.31)	.93
d) Milk booth	21.1	3.5	10.3	26.5	38.6	3.58 (1.54)	4.26 (1.06)	.95
e) Fruit or vegetable market	21.6	7.6	10.8	29.2	30.8	3.40 (1.52)	4.02 (1.24)	.95
f) Meat or fish market	19.2	12.2	22.2	29.7	16.8	3.13 (1.36)	3.35 (1.32)	.95
g) Street food vendors/food stalls	20.0	9.5	14.1	34.9	21.6	3.29 (1.43)	3.56 (1.29)	.95
h) Food canteen	50.3	15.7	14.6	13.8	5.7	2.09 (1.31)	1.89 (1.15)	.97
i) Fast-food restaurant	27.0	13.2	11.1	36.8	11.9	2.93 (1.43)	3.27 (1.39)	.99
j) Coffee shop	15.1	4.9	11.4	46.8	21.9	3.55 (1.30)	3.52 (1.25)	.90
k) Non-fast food restaurant	33.8	16.2	14.6	25.7	9.7	2.61 (1.42)	2.52 (1.43)	.92
l) Street vendors	40.5	15.1	16.8	20.5	7.0	2.38 (1.37)	2.39 (1.25)	.93
m) Shops and stores	28.6	17.0	20.8	24.3	9.2	2.68 (1.35)	2.52 (1.35)	.94
n) Hardware or building material store	25.7	14.3	20.8	32.7	6.5	2.80 (1.31)	1.84 (1.28)	.86
o) Telephone booth	24.3	3.0	6.8	39.5	26.5	3.41 (1.52)	3.81 (1.16)	.77
p) Printing/ q) Xerox shop	14.9	7.8	9.2	41.6	26.5	3.57 (1.35)	3.94 (0.96)	.81
r) Dry cleaner/ ironing	17.6	5.4	8.4	38.1	30.5	3.59 (1.42)	4.05 (1.02)	.89
s) Tailor, cobbler	19.7	14.1	15.1	33.2	17.8	3.15 (1.40)	3.15 (1.46)	.90
t) Post office	41.1	11.4	17.0	25.1	5.4	2.42 (1.38)	2.56 (1.36)	.95
u) Library	53.8	12.4	16.8	15.7	1.4	1.98 (1.21)	2.31 (1.26)	.91

Table 4b ***(continued)***

v)	School	20.8	10.0	21.1	39.7	8.4	3.05 (1.29)	3.32 (1.16)	.84
w)	College or university	62.2	19.2	10.3	6.2	2.2	1.67 (1.03)	1.84 (1.09)	.97
x)	Book store	39.7	14.6	17.6	25.9	2.2	2.36 (1.30)	2.60 (1.29)	.92
y)	Bank or cooperative bank	28.9	9.5	11.4	45.1	5.1	2.88 (1.38)	3.45 (1.04)	.93
z)	Shopping mall	65.9	14.1	10.8	6.5	2.7	1.66 (1.08)	1.66 (1.07)	.99
aa)	Movie theater or multiplex	69.2	14.9	8.4	5.1	2.4	1.57 (1.01)	1.52 (0.92)	.97
bb)	Video/music CD store	56.2	16.5	15.7	9.2	2.4	1.85 (1.13)	1.73 (1.09)	.95
cc)	Pharmacy or medicine shop	11.9	10.5	13.2	54.1	10.3	3.40 (1.17)	3.77 (0.88)	.81
dd)	Salon	23.2	13.2	12.4	42.2	8.9	3.00 (1.36)	3.19 (1.19)	.79
ee)	Your job or school	61.4	8.9	7.0	19.7	3.0	1.94 (1.32)	2.21 (1.45)	.93
ff)	Bus stop or railway station	20.3	6.5	13.0	45.4	14.9	3.28 (1.36)	3.76 (1.10)	.88
gg)	Taxi or auto rickshaw stand	14.1	7.3	12.7	49.7	16.2	3.47 (1.25)	3.79 (1.07)	.90
hh)	Mechanic or repair shop	16.8	14.9	24.3	34.3	9.7	3.05 (1.25)	3.32 (1.05)	.85
ii)	Park or green space	42.7	7.0	14.6	27.0	8.6	2.52 (1.47)	2.66 (1.49)	.99
jj)	Playground	42.4	7.6	14.1	28.9	7.0	2.51 (1.45)	2.94 (1.45)	.96
kk)	Open field/ school field	39.2	10.5	17.6	26.5	6.2	2.50 (1.39)	2.92 (1.37)	.94
ll)	Club or recreation center	48.9	4.9	12.4	29.7	4.1	2.35 (1.43)	2.95 (1.31)	.95
mm)	Gym or fitness facility	35.4	8.9	15.9	33.2	6.5	2.66 (1.41)	3.24 (1.22)	.98
nn)	Private clinic/hospital	23.8	16.8	16.8	37.6	5.1	2.84 (1.30)	3.31 (1.08)	.97
oo)	Government hospital	42.2	15.1	13.2	28.1	1.4	2.31 (1.31)	2.61 (1.21)	.94
pp)	Tap, well/ common water source	68.9	8.4	4.1	12.2	6.5	1.79 (1.33)	1.71 (1.31)	.90
qq)	Place of worship	14.6	12.2	18.6	45.9	8.6	3.22 (1.21)	3.50 (0.92)	.91
rr)	Beach	81.9	10.0	1.9	3.0	3.2	1.36 (0.92)	1.42 (0.97)	.96

Table 4c. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Land Use Mix-Access.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)					Test-retest Reliability Scores (N=62)	
	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Land Use Mix -Access							**.98**
a) possible to do shopping at local stores	13.2	11.1	28.1	47.6	3.10 (1.05)	3.39 (0.88)	.95
b) shops within easy walking distance	11.4	5.7	27.6	55.4	3.27 (0.99)	3.40 (0.84)	.97
c) many places in walking distance of home	15.9	10.5	25.9	47.6	3.05 (1.10)	3.10 (1.13)	.99
d) easy to walk to transit stop	13.5	6.8	31.6	48.1	3.14 (1.04)	3.29 (0.89)	.91

Table 4d. NEWS-India: Answer Frequencies, Mean Scores, and Test-Retest Reliability Scores for Street Connectivity.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)					Test-retest Reliability Scores (N=62)	
	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Street Connectivity							**.85**
a) distance between road junctions is short	18.1	10.3	38.1	33.5	2.87 (1.07)	3.45 (0.72)	.83
b) many four-way road junctions	13.8	8.6	40.3	37.3	3.01 (1.01)	3.45 (0.74)	.79
c) many alternative routes	10.8	7.3	50.0	31.9	3.03 (0.91)	3.11 (0.73)	.89

Table 4e. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Infrastructure and Safety for Walking/Bicycling.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)					Test-retest Reliability Scores (N=62)	
	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Infrastructure and Safety for Walking/Bicycling							**.97**
a) footpaths/pavements on most streets	43.8	10.3	19.2	26.8	2.29 (1.27)	2.48 (1.36)	1.00
b) footpaths/pavements well-maintained	58.8	10.8	17.3	13.0	1.85 (1.12)	1.48 (0.95)	.95
c) bicycle or pedestrian pathways are easy to get to	75.9	10.8	10.0	3.2	1.41 (0.80)	1.19 (0.54)	1.00
d) footpaths separated from road by parked cars, motorcycles, or auto-rickshaws.	56.2	9.7	25.1	8.9	1.87 (1.08)	2.08 (1.06)	.70
e) footpaths separated by grass/dirt strip.	74.6	12.4	7.6	5.4	1.44 (0.85)	1.13 (0.38)	1.00
f) safe to ride a bicycle	64.6	8.6	17.8	8.9	1.71 (1.05)	1.42 (0.82)	.93
g) streets well lit at night	17.6	6.8	28.1	47.6	3.06 (1.12)	3.21 (1.04)	.96
h) walkers and bicyclists easily seen by people in homes.	16.2	9.5	54.1	20.3	2.78 (0.95)	2.97 (0.72)	.88
i) zebra crossings present	66.2	7.0	17.0	9.7	1.70 (1.07)	1.39 (0.86)	.98
j) zebra crossings promote safety	64.9	7.3	17.8	10.0	1.73 (1.08)	1.37 (0.87)	.93
k) footpaths not obstructed	60.3	11.6	13.5	14.6	1.82 (1.14)	1.48 (1.02)	.99
l) facilities to bicycle (lanes etc.) available	80.0	8.4	8.4	3.2	1.35 (0.77)	1.11 (0.45)	.48

Table 4f. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Aesthetics.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)					Test-retest Reliability Scores (N=62)	
	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Aesthetics							**.93**
a) presence of trees	20.5	11.9	36.5	31.1	2.78 (1.10)	2.81 (1.13)	.91
b) trees give shade	25.4	12.2	36.5	25.9	2.63 (1.12)	2.63 (1.18)	.94
c) interesting things to look at	49.7	20.3	24.3	5.7	1.86 (0.98)	1.48 (0.81)	.90
d) neighborhood is free from litter/garbage, graffiti, or stagnant water.	66.8	14.3	10.0	8.9	1.61 (0.99)	1.37 (0.81)	.96
e) attractive natural sights	62.7	19.2	13.5	4.6	1.60 (0.89)	1.37 (0.71)	.78
f) attractive buildings	56.2	18.4	19.2	6.2	1.75 (0.97)	1.27 (0.58)	.79

Table 4g. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Safety from Traffic.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)					Test-retest Reliability Scores (N=62)	
	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Safety from Traffic							**.90**
a) traffic on street I live makes it difficult to walk	25.5	14.4	20.3	39.8	2.75 (1.23)	2.95 (1.15)	.95
b) traffic on nearby streets makes it difficult to walk	21.4	10.8	21.1	46.6	2.93 (1.20)	3.53 (0.82)	.71
c) speed of traffic on street I live is slow	30.1	17.9	34.1	17.9	2.40 (1.10)	2.37 (1.01)	.85
d) speed of traffic on nearby streets is slow	36.3	21.1	28.2	14.4	2.21 (1.09)	1.98 (1.00)	.81
e) drivers exceed speed limits	13.6	18.7	29.0	38.8	2.93 (1.06)	3.11 (0.96)	.87
f) a lot of exhaust fumes	16.3	12.7	28.2	42.8	2.98 (1.10)	3.15 (1.13)	.93

Table 4h. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Safety from Crime.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)					Test-retest Reliability Scores (N=62)	
	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
Safety from Crime							**.92**
a) high crime rate	29.7	12.2	28.4	29.7	2.58 (1.20)	2.63 (1.24)	.89
b) unsafe to walk during day	33.0	23.5	21.2	22.4	2.33 (1.15)	1.98 (1.06)	.84
c) unsafe to walk at night	25.5	16.0	25.5	32.9	2.66 (1.18)	3.02 (1.20)	.91
d) neighborhood safe for a 10-year old boy to walk alone in daytime	19.5	13.2	42.4	24.9	2.73 (1.04)	2.73 (0.91)	.85

Table 4i. NEWS-India: answer frequencies, mean scores, and test-retest reliability scores for Single Items.

Item/Scale	Answer frequencies and mean score of items on first assessment (%) (N=370)					Test-retest Reliability Scores (N=62)	
	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Baseline Mean (SD)	Retest Mean (SD)	ICC[a]
a) Single Items							
a) parking is difficult in local shopping areas.	23.8	11.6	20.5	44.1	2.85 (1.22)	3.03 (1.20)	.97
b) streets are hilly	80.3	7.0	8.6	4.1	1.36 (0.81)	1.06 (0.25)	1.00
c) major barriers to walking (bad roads, poor sidewalks, poor drainage, water logging)	21.6	11.4	15.7	51.4	2.97 (1.22)	3.63 (0.79)	.81
d) streets do not have many dead-ends.	31.6	27.6	28.4	12.4	2.22 (1.03)	2.03 (0.89)	.70
e) walking paths connect dead-ends to main roads or streets	37.0	13.0	37.3	12.7	2.26 (1.09)	2.73 (0.83)	.50
f) see and speak to other people while walking in neighborhood	16.2	5.4	52.7	25.7	2.88 (0.97)	2.89 (0.85)	.85

5.3 Descriptive Statistics

The total sample comprised 370 participants with 54.2% females and mean age of 37.9 ± 15.3 years (Table 5). The majority of participants were married (61.2%) and employed (62.5%), either in blue collar (31.4%) or white collar jobs (31.1%). About 13% of participants were uneducated, 21.5% of participants had a high school education or equivalent, while 49.7% had a graduate or professional degree. Income levels reported 48.2% earning less than 600 US Dollars (approximately 36,017 Indian rupees) per month. Significant differences in demographic characteristics across all neighborhood quadrants were observed. Descriptive statistics of all participants are presented in Table 5.

5.4 Built Environment Characteristics

Table 6 shows that the high-walkability/high-SES neighborhood had higher scores on five of the eight NEWS subscales: land use mix diversity, land use mix access, street connectivity, aesthetics, and safety from crime. Highest residential density (weighted mean=866.9 per sq.km.) and walking/bicycling infrastructure (mean=2.2) was reported in the high-walkability/low-SES neighborhood. Safety from traffic (mean=2.5) was highest in the low walkability/low SES neighborhood. Overall, high-walkability/high-SES neighborhood reported the highest aggregate NEWS score (mean=19.8) while the lowest NEWS score was found in low-walkability/low-SES neighborhood (mean=14.6). NEWS subscale and single item scores are listed in Table 6.

Table 5. Descriptive characteristics of the sample (N=370).

Descriptive Characteristics	Neighborhood Quadrants				Full Sample	Statistic
	1	2	3	4		
	High walkability High SES	Low walkability High SES	High walkability Low SES	Low walkability Low SES		
	n=122	n=88	n=76	n=84	N=370	
Age[a] (years) Mean (SD)	40.2 (17.3)	34.1 (14.2)	40.5 (14.8)	36.4 (12.6)	37.9 (15.3)	3.88*
Gender[b] (n, %)						13.06**
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[b] (n, %)						
Married	69 (56.6)	41 (46.4)	58 (77.3)	58 (69.0)	226 (61.2)	19.43***
Not Married	53 (43.4)	47 (53.4)	17 (22.7)	26 (31.0)	143 (38.8)	
Religion[b] (n, %)						
Hindu	87 (71.3)	77 (87.5)	65 (86.7)	75 (89.3)	304 (82.2)	15.60***
non-Hindu	35 (28.7)	11 (12.5)	10 (13.3)	9 (10.7)	65 (17.6)	
Educational Level[c] (n, %)						205.07***
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[c] in US Dollars (n, %)						229.52***
≤ 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[c] (n, %)						41.24***
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 & Maheshwaran (2014).

[a] Values based on one-way Analysis of Variance (ANOVA)-Welch's F-Statistic

[b] Values based on Chi-Square test

[c] Values based on Kruskal-Wallis test

*p < 0.05, **p < 0.01, ***p < 0.001.

Table 6. Descriptive characteristics and differences in NEWS-India scores and single items across neighborhoods (N=370).

NEWS Subscales and Single Items	Neighborhood Quadrants 1: High walkability High SES n=122	2: Low walkability High SES n=88	3: High walkability Low SES n=76	4: Low walkability Low SES n=84	Full Sample N=370	F[a]	Quadrant Pairwise Comparison[b]	Confidence Interval Lower	Confidence Interval Upper
	Mean (SD) (Range)	Mean (SD) (Range)	Mean (SD) (Range)	Mean (SD) (Range)	Mean (SD) (Range)				
Residential Density˜	566.0 (164.0) (390.0-1119.0)	514.5 (126.0) (208.0-1117.0)	866.9 (243.5) (420.0-1558.0)	620.9 (228.9) (386.0-1523.0)	628.0 (229.1) (208.0-1558.0)	43.9***	1&2*	-0.4	103.3
							1&3***	-383.4	-218.5
							2&3***	-433.3	-271.5
							2&4**	-180.1	-32.5
							3&4***	148.7	343.4
Land Use Mix–Diversity	3.4 (0.4) (2.3-4.3)	2.7 (0.5) (1.4-4.1)	2.7 (0.8) (1.4-3.9)	1.8 (0.8) (1.0-4.9)	2.8 (0.9) (1.0-4.9)	116.02***	1&2***	0.5	0.9
							1&3***	0.5	0.9
							1&4***	1.4	1.9
							2&4***	0.7	1.2
							3&4***	0.6	1.2
Land Use Mix–Access	3.7 (0.5) (2.0-4.0)	3.1 (0.7) (1.0-4.0)	3.4 (0.6) (1.3-4.0)	2.2 (1.0) (1.0-4.0)	3.1 (0.9) (1.0-4.0)	58.1***	1&2***	0.4	0.9
							1&3***	0.1	0.5
							1&4***	1.2	1.8
							2&3*	-0.6	-0.0
							2&4***	0.5	1.2
							3&4***	0.8	1.5
Street Connectivity	3.4 (0.4) (2.7-4.0)	2.9 (0.7) (1.0-4.0)	3.2 (0.7) (1.3-4.0)	2.2 (0.9) (1.0-4.0)	3.0 (0.8) (1.0-4.0)	49.6***	1&2***	0.3	0.7
							1&4***	0.9	1.5
							2&3***	-0.6	-0.0
							2&4**	0.4	1.0
							3&4***	0.7	1.3
Infrastructure for Walking/ Bicycling	2.0 (0.6) (1.0-3.9)	2.0 (0.5) (1.0-3.9)	2.2 (0.6) (1.2-3.5)	1.8 (0.7) (1.0-3.4)	2.0 (0.6) (1.0-3.9)	5.3***	1&3*	-0.5	-0.0
							3&4***	0.1	0.6
Aesthetics	2.3 (0.6) (1.0-4.0)	2.0 (0.7) (1.0-3.8)	2.0 (0.7) (1.0-3.7)	1.9 (0.7) (1.0-3.7)	2.0 (0.7) (1.0-4.0)	7.6***	1&2*	0.1	0.5
							1&3*	0.1	0.6
							1&4***	0.2	0.6
Pedestrian/ Traffic Safety	2.0 (0.8) (1.0-4.0)	2.4 (0.7) (1.0-3.8)	1.8 (0.8) (1.0-3.8)	2.5 (0.6) (1.0-4.0)	2.2 (0.8) (1.0-4.0)	16.0***	1&2**	-0.6	-0.1
							1&4***	-0.7	-0.2
							2&3***	0.2	0.8
							3&4***	-1.0	-0.4
Safety from Crime	3.0 (0.9) (1.0-4.0)	2.8 (0.8) (1.0-4.0)	1.8 (0.7) (1.0-3.3)	2.3 (0.7) (1.0-4.0)	2.5 (0.9) (1.0-4.0)	43.6***	1&3***	0.9	1.5
							1&4***	0.5	1.1
							2&3***	0.7	1.3
							2&4***	0.2	0.8
							3&4***	-0.8	-0.2

Table 6. ***(continued)***

Parking is difficult in local shopping areas	3.3 (1.0) (1.0-4.0)	2.9 (1.2) (1.0-4.0)	2.8 (1.1) (1.0-4.0)	2.1 (1.3) (1.0-4.0)	2.9 (1.2) (1.0-4.0)	17.9***	1&3* 1&4*** 2&4*** 3&4***	0.0 0.8 0.4 0.3	0.89 1.7 1.4 1.3
Streets in the neighborhood are hilly	4.0 (0.0) (1.0-4.0)	3.5 (0.8) (1.0-4.0)	3.3 (1.0) (1.0-4.0)	3.5 (0.9) (1.0-4.0)	3.6 (0.8) (1.0-4.0)	14.9***	1&2*** 1&3*** 1&4***	0.2 0.4 0.2	0.7 1.0 0.8
Streets in the neighborhood do not have many dead-ends	2.2 (0.8) (4.0-4.0)	2.2 (0.9) (1.0-4.0)	2.6 (1.2) (1.0-4.0)	1.9 (1.1) (1.0-4.0)	2.2 (1.0) (1.0-4.0)	5.1**	1&3* 3&4***	-0.8 0.2	-0.0 1.2
Major barriers to walking (e.g., bad roads, poor sidewalks, water logging)	1.7 (1.1) (1.0-4.0)	2.1 (1.2) (1.0-4.0)	1.5 (0.9) (1.0-4.0)	2.8 (1.2) (1.0-4.0)	2.0 (1.2) (1.0-4.0)	21.3***	1&2** 1&4*** 2&3** 2&4** 3&4***	-0.8 -1.5 0.2 -1.2 -1.7	0.0 -0.6 1.1 -0.2 -0.9
I see and speak to other people while walking in the neighborhood	3.0 (0.8) (1.0-4.0)	3.3 (0.8) (1.0-4.0)	2.9 (0.9) (1.0-4.0)	2.3 (1.2) (1.0-4.0)	2.9 (0.9) (1.0-4.0)	13.4***	1&4*** 2&4*** 3&4***	0.4 0.6 0.2	1.1 1.4 1.1
There are walking paths in my neighborhood that connect dead-ends to main roads or streets	2.6 (1.0) (1.0-4.0)	2.5 (0.9) (1.0-4.0)	2.0 (1.2) (1.0-4.0)	1.7 (1.0) (1.0-4.0)	2.3 (1.1) (1.0-4.0)	16.1***	1&3*** 1&4*** 2&3* 2&4***	0.2 0.6 0.0 0.4	1.1 1.3 0.9 1.1
NEWS-India Aggregate Score[^]	19.8 (2.5) (14.5-27.5)	17.8 (2.3) (25.0-17.8)	17.1 (1.9) (13.8-22.1)	14.6 (3.0) (10.3-21.7)	17.6 (3.1) (1.0-4.0)	60.7***	1&2*** 1&3*** 1&4*** 2&4*** 3&4***	1.1 1.9 4.1 2.1 1.4	2.8 3.5 6.2 4.2 3.4

Note: All environmental scales and items were positively scored, i.e., higher score=more walkable/activity-friendly.
SD = Standard Deviation
[~]Residential Density (RD) calculated as a weighted score of 7 items
RD=RD1+(10*RD2)+(25*RD3)+(50*RD4)+(75*RD5)+(100*RD6)+(125*RD7).
These weighting values are based on approximate density of households per unit area relative to a single-family detached residence as prescribed in the IPEN protocol for NEWS scoring.[52, 53, 139] All other subscale scores calculated as mean of item responses.
*p < 0.05, **p < 0.01, ***p < 0.001.
[a] represents one-way Analysis of Variance (ANOVA)-Welch's F-Statistic
[b] represents Games-Howell post-hoc test statistic
[^]represents aggregate NEWS-Score of all NEWS subscales excluding Residential Density since it is a weighted score

5.5 Physical Activity, Sedentary Behavior, and Weight Status

Table 7 demonstrates the varying range in the PA outcomes across the four neighborhood quadrants. Sedentary time and weight status are also reported.

5.5.1 Travel Physical Activity

Walking and Bicycling

Residents of low-SES neighborhoods (quadrants 3, 4) reported higher levels of walking, bicycling, and total travel PA compared to residents of high-SES neighborhoods (Table 7). Residents in the low walkability/low SES neighborhood reported the most number of minutes of travel-related walking (mean=223 minutes/week, SD=520.1) and bicycling (mean=75 minutes/week, SD=183.6) for transport purposes during the past 7 days compared to residents of the other neighborhoods.

Total Travel PA

Overall, total travel PA was highest among residents of the low-walkability/low SES neighborhood (mean=275 minutes/week, SD=508.7) and lowest among residents of the high-walkability/high SES neighborhood (mean=28 minutes/week, SD=55.1).

Welch's ANOVA statistics show significant differences in levels of travel-related walking ($F=13.6$, $p<.001$), bicycling ($F=12.2$, $p<.001$), and total travel PA ($F=15.5$, $p<.001$) between the neighborhoods. Results of the Games-Howell post-hoc tests show that the high-walkability/high-SES neighborhood (quadrant 1) was significantly different from the other three neighborhoods (quadrants 2, 3, 4) for travel-related walking, bicycling, and total PA.

5.5.2 Leisure Physical Activity

Walking

Leisure-time walking was highest among residents of the high-walkability/low-SES neighborhood (quadrant 3) with a mean value of approximately 129 minutes/week (SD=287.3) in the past 7 days. Lowest leisure-time walking levels were reported by residents of the low-walkability/high-SES neighborhood (quadrant 2) with a mean value of approximately 50 minutes/week (SD=118.7) in the past 7 days. There were no significant differences in leisure-time walking across the four neighborhoods (F=2.2, p=.09).

All Moderate-to-Vigorous PA

Significant differences were observed in leisure-time Moderate-to-Vigorous PA (MVPA; includes only leisure-time moderate and vigorous PA, excludes leisure-time walking) across neighborhoods (F=14.9, p<.001); specifically MVPA was statistically different between residents of high and low SES neighborhoods. Residents in high-SES/low-walkable neighborhoods reported highest levels of leisure-time MVPA per week (mean=147 minutes/week, SD=226.8), followed by residents in high-SES/high-walkable neighborhoods (mean=129 minutes/week, SD=287.3). In the low-SES quadrants, residents in low walkable neighborhoods had the least engagement in leisure-time MVPA (mean=42 minutes/week, SD=140.5).

Total Leisure PA

Overall, total levels of leisure-time PA (LTPA; includes leisure-time walking and leisure-time MVPA) followed a pattern similar to leisure-time MVPA. Significant differences were observed in LTPA across neighborhoods (F=14.6, p<.001); specifically LTPA was statistically different between residents of high and low SES neighborhoods. Residents in high-SES/high-walkable neighborhoods reported highest levels of LTPA per week (mean=221 minutes/week, SD=264.6), followed by residents in high-SES/low-walkable neighborhoods (mean=202 minutes/week,

SD=238.9). In the low-SES quadrants, residents in low walkable neighborhoods had the least engagement in LTPA (mean=111 minutes/week, SD=245.5), followed by residents in high walkable neighborhoods (mean=170 minutes/week, SD=450.9).

5.5.3 Total Physical Activity

Total weekly mean levels of MVPA and all PA (including walking and bicycling for leisure and travel) were highest in the low-walkability/low-SES neighborhood (quadrant 4), at approximately 288 minutes/week (SD=532.9) and 358 minutes/week (SD=607.9), respectively. Lower MVPA (mean=157 minutes/week, SD=237.7) and all PA (mean=259 minutes/week, SD=242.9) was reported in the high-walkability/high-SES neighborhood. There were significant differences between neighborhood groups; significant pairwise differences between neighborhoods are presented in Table 7.

5.5.4 Sedentary (Sitting) Behavior

Residents of high-walkability/high-SES neighborhood reported the highest number of daily mean minutes spent sitting (mean=514 minutes, SD=242.4) which approximates 8.5 hours/day. Sedentary time was lowest in the high walkability/low-SES neighborhood (mean=279.8, SD=194.6) which equals 4.7 hours/day. High-SES residents in low walkability neighborhoods reported a daily mean level of 324.3 minutes (SD=282.1) spent sitting (5 hours/day). Residents in the low-SES/low-walkability neighborhood reported a daily mean level of 287.8 minutes (SD=227.4) spent sitting (4.8 hours/day). Sedentary behavior among residents in the high-walkability/high-SES neighborhood was significantly different from all other neighborhoods ($F=23.3$, $p<.001$).

5.5.5 Weight Status

Mean BMI was 24.6 (±5.7) kg/m^2. Self-reported BMI was highest (mean=26 kg/m^2, SD=5.0) among residents in the high-walkability/high-SES neighborhood and least in the two low-SES neighborhoods (mean=23.5 kg/m^2, SD=6.4 and 6.5 in quadrants 3 and 4 respectively). Significant differences in BMI were found between the high-walkability/high-SES neighborhood and the two low-SES neighborhood quadrants ($F=6.9$, $p<.001$).

Table 7. Differences in physical activity, sedentary (sitting) time, and weight status by neighborhood (N=370).

	Neighborhood Quadrants								
	1	2	3	4					
Outcome	**High walkability High SES**	**Low walkability High SES**	**High walkability Low SES**	**Low walkability Low SES**	**Full Sample**	**F[a]**	**Quadrant Pairwise Comparison[b]**	**Confidence Intervals**	
	n=122	n=88	n=76	n=84	N=370			**Lower**	**Upper**
TRAVEL PA Mean (SD)									
Walking	26. 9 (54.5)	96.9 (141.3)	216.7 (331.3)	222.8 (520.1)	125.3 (309.1)	13.6***	1 & 2***	-2.2	-0.4
							1 & 3***	-3.1	-1.2
							1 & 4*	-2.0	-0.1
Bicycling	1.0 (10.9)	14.2 (35.7)	14.4 (58.2)	74.9 (183.6)	22.9 (95.6)	12.2***	1 & 2**	-1.2	-0.2
							1 & 3*	-0.9	-0.0
							1 & 4***	-1.9	-0.5
Total Travel PA	27.9 (55.1)	106.3 (137.7)	227.8 (340.4)	275.0 (508.7)	139.8 (308.9)	15.5***	1 & 2***	-2.5	-0.8
							1 & 3***	-3.1	-1.1
							1 & 4***	-2.5	-0.5
LEISURE PA Mean (SD)									
Walking	92.7 (158.3)	50.0 (118.7)	128.9 (287.3)	101.4 (275.8)	91.9 (212.5)	2.2	NS	N/A	N/A
MVPA	128.6 (230.9)	146.5 (226.8)	57.1 (250.3)	42.3 (140.5)	101.6 (222.5)	14.9***	1 & 3***	0.8	2.5
							1 & 4***	0.6	2.4
							2 & 3***	0.9	2.8
							2 & 4***	0.7	2.7
Total LTPA	221.3 (264.6)	201.9 (238.9)	170.1 (450.9)	111.4 (245.5)	184.6 (304.3)	14.6***	1 & 3***	1.1	3.2
							1 & 4***	0.9	3.1
							2 & 3***	0.7	3.0
							2 & 4***	0.6	2.9
TOTAL PA Mean (SD)									
MVPA	156.5 (237.7)	269.6 (278.9)	253.2 (362.7)	287.8 (532.9)	228.4 (353.4)	4.4**	1 & 2*	-2.0	-0.1
							2 & 4**	0.3	2.7
All PA	249.2 (272.9)	331.9 (282.1)	352.3 (473.4)	357.9 (607.9)	310.6 (410.1)	3.8**	2 & 4**	0.3	2.7
SEDENTARY BEHAVIOR Mean (SD)									
Sitting time	514.2 (242.4)	324.3 (282.1)	279.8 (194.6)	287.8 (227.4)	372. 9 (261.1)	23.3***	1 & 2***	91.4	288.4
							1 & 3***	152.1	316.7
							1 & 4***	137.9	314.9

WEIGHT STATUS Mean (SD)									
BMI (kg/m^2)	26.0 (5.0)	24.3 (4.3)	23.5 (6.4)	23.5 (6.5)	24.6 (5.7)	6.9***	1 & 3**	0.0	0.2
							1 & 4**	0.0	0.2
BMI CATEGORIES^ N (%)									
Under weight	4 (3.3)	3 (4.5)	12 (16.9)	16 (20.5)	35 (10.4)	N/A	N/A	N/A	N/A
Normal weight	57 (47.1)	46 (69.7)	35 (49.3)	39 (50.0)	177 (52.7)	N/A	N/A	N/A	N/A
Over-weight	40 (33.1)	7 (10.6)	16 (22.5)	14 (17.9)	77 (22.9)	N/A	N/A	N/A	N/A
Obese	20 (16.5)	10 (15.2)	8 (11.3)	9 (11.5)	47 (14.0)	N/A	N/A	N/A	N/A

Note: SES=Socio-Economic Status, PA=Physical Activity, MVPA=Moderate-to-Vigorous Physical Activity, LTPA=Leisure-Time Physical Activity (includes leisure-time walking and MVPA), BMI=Body Mass Index measured in kg/m^2, NS=Not Significant, N/A=Not Applicable

Total LTPA includes leisure-time walking and leisure-time MVPA.

[a] represents one-way Analysis of Variance (ANOVA)-Welch's F-Statistic

[b] represents Games-Howell post-hoc test statistic

*p < 0.05, **p < 0.01, ***p < 0.001

^Based on WHO cut-off points[13]

5.6 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 8. Among residents that were meeting WHO recommended levels of weekly PA from travel-related walking and bicycling, 44.8% (N=30) belonged to the high-walkability/low-SES neighborhood, followed by 44.7% (N=34) of residents from the low-walkability/low-SES neighborhood. The lowest contribution of travel PA to weekly PA was reported in the high-walkability/high-SES neighborhood where 4.9% (N=6) of residents reported achieving weekly PA recommendations from travel-related activities. 22.7% (N=17) of residents from the low-walkability/high-SES neighborhood reported meeting weekly PA recommendations from travel PA.

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. The lowest percentage of residents (19.1%, N=13) meeting weekly PA recommendations by engaging in leisure activities belonged to the high walkability/low-SES neighborhood. Overall, a higher number of participants in the low-SES neighborhoods met WHO recommended guidelines for PA through travel-related activities. Leisure PA was higher in high-SES neighborhoods.

Overall, 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.

Table 8. Descriptive statistics of sample population for leisure, travel, and total physical activity (meeting, not meeting WHO recommendations).

Physical Activity Variables	Neighborhood Quadrants 1 High walkability High SES n=122	2 Low walkability High SES n=88	3 High walkability Low SES n=76	4 Low walkability Low SES n=84	Full Sample N=370
TRAVEL WALKING (n, %)					
Meeting WHO guidelines[a]	6 (4.9)	18 (23.4)	30 (42.3)	27 (34.2)	81 (23.2)
Not meeting WHO guidelines	116 (95.1)	59 (76.6)	41 (57.7)	52 (65.8)	268 (76.8)
TRAVEL BICYCLING (n, %)					
Meeting WHO guidelines	0 (0)	0 (0)	2 (2.9)	13 (17.1)	15 (4.3)
Not meeting WHO guidelines	122 (100)	78 (100)	67 (97.1)	63 (82.9)	330 (95.7)
TOTAL 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 TIME WALKING (n, %)					
Meeting WHO guidelines	35 (28.7)	14 (17.3)	14 (19.7)	15 (20.8)	78 (22.5)
Not meeting WHO guidelines	87 (71.3)	67 (82.7)	57 (80.3)	57 (79.2)	268 (77.5)
LEISURE TIME MVPA (n, %)					
Meeting WHO guidelines	31 (25.4)	26 (31.0)	5 (7.4)	7 (10.3)	69 (20.2)
Not meeting WHO guidelines	91 (74.6)	58 (69.0)	63 (92.6)	61 (89.7)	273 (79.8)
TOTAL 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 MVPA (n, %)					
Meeting WHO guidelines	37 (30.3)	43 (57.3)	31 (47.0)	28 (41.2)	139 (42.0)
Not meeting WHO guidelines	85 (69.7)	32 (42.7)	35 (53.0)	40 (58.8)	192 (58.0)
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, MVPA=Moderate-To-Vigorous Physical Activity

[a] At least 150 minutes of PA per week based on global recommendations for PA among adults established by the WHO.

5.7 Logistic Regression Models

Crude and adjusted (age, gender, education, and neighborhood quadrants as controls) 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 9 and 10 respectively.

5.7.1 Models 1a-1c (Adjusted for age and gender)

Model 1a (Table 9) shows BE predictors of PA 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 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 neighborhoods with aesthetic qualities had approximately 5 times the odds of engaging in leisure PA (aOR=5.2, CI=1.7, 15.5). Infrastructure for walking/bicycling and safety from traffic also improved odds of leisure PA, but these relationships were not statistically significant. 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. Although there were no significant associations between BE predictors and total PA, the overall adjusted odds of engagement in total PA were in the positive direction. Land-use mix diversity and aesthetics were the only BE factors negatively associated with total PA.

Table 9. Model 1a: 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	aOR[a]	OR	aOR[a]	OR	aOR[a]
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, PA=Physical Activity, NEWS=Neighborhood Environment Walkability Scale

*p < 0.05, **p < 0.01, ***p < 0.001

~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 minutes walking distance or ≥ 10 minutes. 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

Example interpretation: Participants agreeing (agree/strongly agree) that their neighborhood offers aesthetics, were 4.1 time more likely to meet Leisure PA recommendations than those participants disagreeing (disagree/strongly disagree) with the statement that their neighborhood is aesthetic.

Model 1b (Table 10) 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 significant. Infrastructure for walking/bicycling was significantly related with leisure PA, but adjusted odds were reduced by 60% (aOR=0.4, CI=0.2, 1.0). No BE predictors were significantly related to the adjusted odds of total PA.

Table 10. Model 1b: 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	aOR[a]	OR	aOR[a]	OR	aOR[a]
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 PA=Physical Activity, NEWS=Neighborhood Environment Walkability Scale

*p < 0.05, **p < 0.01, ***p < 0.001

~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 minutes walking distance or ≥ 10 minutes. 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 11 shows pooled analysis of built environment predictors of meeting WHO-recommended levels of leisure, travel, and total PA across all neighborhoods. Models were adjusted for age and gender. 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 (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. The relationship between land use mix-diversity and travel PA was only significant in Model 1c (adjusted for age and gender), but not significant when other socio-demographic (education) and design covariates (neighborhood quadrants) were introduced in the regression analysis (Models 2 and 3). 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). Land use mix-access, street connectivity, aesthetics, safety from crime increased odds of leisure PA, but these associations were not significant. 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).

Table 11. Model 1c: 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	aOR[a]	OR	aOR[a]	OR	aOR[a]
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 PA=Physical Activity, NEWS=Neighborhood Environment Walkability Scale

*p < 0.05, **p < 0.01, ***p < 0.001

~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 minutes walking distance or ≥ 10 minutes. 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

5.7.2 Model 2 (Adjusted for age, gender, and education)

Table 12 shows built environment predictors of meeting WHO-recommended levels of leisure, travel, and total PA across all neighborhoods with models adjusted for age, gender, and education. Compared with model 1c (Table 11), no BE characteristics are significantly related to the PA outcomes. The addition of education in the regression model negated significant effects observed in model 1c. In some instances, the adjusted odds ratios also moved closer to 1.0.

Table 12. Model 2: Built environment predictors of meeting WHO-recommended levels of leisure, travel, and total physical activity in Chennai, India (N=370), aOR[a] (95% CI).

Independent Variables	**Leisure PA**	**Travel PA**	**Total PA**
NEWS-India Subscales˜	**aOR[a]**	**aOR[a]**	**aOR[a]**
Residential density	0.8 (0.5, 1.2)	1.6 (0.9, 2.7)	0.9 (0.6, 1.4)
Land use mix–diversity	1.1 (0.6, 2.2)	1.1 (0.6, 2.0)	0.7 (0.4, 1.2)
Land use mix–access	0.8 (0.4, 1.4)	1.1 (0.6, 2.1)	1.2 (0.7, 2.1)
Street connectivity	1.0 (0.5, 2.0)	1.0 (0.5, 1.9)	1.1 (0.6, 2.0)
Infrastructure for walking/bicycling	0.9 (0.5, 1.6)	1.3 (0.7, 2.4)	0.8 (0.5, 1.5)
Aesthetics	1.0 (0.6, 1.8)	0.5 (0.2, 1.1)	0.8 (0.5, 1.4)
Safety from traffic	0.9 (0.5, 1.6)	1.4 (0.8, 2.4)	0.8 (0.5, 1.3)
Safety from crime	0.8 (0.5, 1.4)	0.8 (0.4, 1.4)	0.7 (0.4, 1.2)
Aggregate NEWS-India Score	0.7 (0.5, 1.2)	1.5 (0.9, 2.6)	0.9 (0.6, 1.4)

Note: aOR=Adjusted Odds Ratios, PA=Physical Activity, NEWS=Neighborhood Environment Walkability Scale
*p < 0.05, **p < 0.01, ***p < 0.001
˜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 minutes walking distance or ≥ 10 minutes. 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, gender, and education

5.7.3 Model 3 (Adjusted for age, gender, and neighborhood quadrants)

In the next model, education was removed as a covariate. Instead, a design variable (neighborhood quadrant) was introduced. Table 13 shows built environment predictors of meeting WHO-recommended levels of leisure, travel, and total physical activity across all neighborhoods with models adjusted for age, gender, and neighborhood quadrants. Compared with model 1c (Table 11), no BE characteristics are significantly related to the PA outcomes. By controlling for neighborhood quadrants in the regression model, significant effects observed previously in model 1c were negated.

Table 13. Model 3: Built environment predictors of meeting WHO-recommended levels of leisure, travel, and total physical activity in Chennai, India (N=370), aOR[a] (95% CI).

Independent Variables	**Leisure PA**	**Travel PA**	**Total PA**
NEWS-India Subscales˜	**aOR[a]**	**aOR[a]**	**aOR[a]**
Residential density	0.9 (0.6, 1.5)	1.2 (0.7, 2.2)	0.9 (0.6, 1.5)
Land use mix–diversity	1.6 (0.7, 3.8)	0.5 (0.3, 1.1)	0.7 (0.3, 1.5)
Land use mix–access	0.8 (0.4, 1.6)	1.6 (0.8, 3.4)	1.3 (0.7, 2.3)
Street connectivity	1.1 (0.6, 2.3)	1.5 (0.8, 3.1)	1.1 (0.5, 2.1)
Infrastructure for walking/bicycling	1.0 (0.5, 1.8)	1.1 (0.5, 2.1)	0.9 (0.5, 1.5)
Aesthetics	1.0 (0.6, 1.8)	0.6 (0.3, 1.2)	0.8 (0.5, 1.5)
Safety from traffic	0.9 (0.5, 1.5)	1.4 (0.8, 2.5)	0.8 (0.5, 1.3)
Safety from crime	0.7 (0.4, 1.1)	1.3 (0.7, 2.5)	0.7 (0.4, 1.1)
Aggregate NEWS-India Score	0.9 (0.5, 1.5)	1.2 (0.7, 2.2)	0.9 (0.5, 1.4)

Note: aOR=Adjusted Odds Ratios, PA=Physical Activity, NEWS=Neighborhood Environment Walkability Scale
*p < 0.05, **p < 0.01, ***p < 0.001
˜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 minutes walking distance or ≥ 10 minutes. 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, gender, and neighborhood quadrants

Chapter 6: Discussion

This study examined the association of 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.[27] To the study investigator's knowledge, there has been no study estimating neighborhood BE variables and PA prevalence in India. This is one of the first studies to examine modifiable environmental determinants of chronic diseases in India. Results from this study extend the current evidence by demonstrating that the BE is an important correlate of PA in LMICS.

The associations of PA levels with BE characteristics for a representative sample of adults in Chennai, India, differ markedly from associations reported for high-income countries. Significant differences across sampled neighborhoods in domain-specific PA were observed. Travel PA was higher among low-SES populations, while high-SES populations reported greater leisure-time PA. Sedentary time and BMI were highest in high-walkable/high-SES neighborhoods. The variation in domain-specific PA prevalence across neighborhoods of varying walkability and SES demonstrates the value of studying such behaviors in India. Findings from this study offer empirical evidence on BE supports for domain-specific PA in India.

This study sought to provide a preliminary test of the oft-stated hypothesis that neighborhood walkability as defined by land use and community design, is related to PA and body weight in India.[30, 37, 214] This inquiry extends transportation research findings in an Indian context by suggesting that neighborhood-level differences in walkability and income may impact levels of leisure and travel PA and weight status of individuals.[215]

6.1 Test-Retest Reliability

There are no previously published reports of the reliability of existing BE instruments for Indian cities. As this appears to be the first published description of the development of a comprehensive instrument designed to measure factors in the physical environment that may influence walking and bicycling in neighborhoods in India, there are several lessons to be learned from this study. The test-retest reliability of the items in the NEWS-India instrument were generally high with almost perfect strength of agreement, indicating that the items are generally reliable. While the overall strength of agreement across items was high, some items assessing subjective qualities of the BE such as general levels of attractiveness (e.g., attractive natural sights, attractive buildings) and difficulty for PA (e.g., traffic makes it difficult to walk) had lower ICC's in the substantial agreement range. This could be due to participants experiencing difficulty in subjectively assessing the items measuring attractiveness and difficulty for PA. Since these items were based entirely on subjective overall impressions, it could be expected that the scores for them would vary based on the participant's previous experiences of walking and cycling. Only two items—presence of bicycling facilities and walking paths connecting dead-end streets—had low ICCs indicating moderate agreement. These may be because these items were assessing rare BE features that did not exist in the study area. Reliability studies from LMICs such as Hong Kong[57, 216], Brazil[174], and Nigeria[46] have also demonstrated moderate agreement of ICCs for the same items assessing pedestrian and bicycling infrastructure.

While these results indicate that the items in the NEWS-India instrument are generally reliable, this aspect of the study has two limitations: the limited variation among the neighborhood quadrants assessed and the number of participants that were assessed for test-retest reliability.

While 62 observations were collected to assess test-retest reliability, participants belonged to four neighborhood quadrants pre-stratified based on income and walkability. This points to the need for care in extrapolating the reliability results beyond the study area and the need for reliability studies to be repeated when an audit instrument is used in other urban environments. A larger number of neighborhood quadrants would have allowed more precise estimation of reliability. However, due to lack of resources it was not possible to increase the number of neighborhood quadrants or participants in this study. Therefore, the test-retest reliability of the NEWS-India instrument should be investigated further across India.

Overall, results indicate that NEWS-India was generally a reliable and practical instrument for collecting data and that participants found it easy to use. While this instrument provides a method of collecting environmental data, it remains important to explore which environmental attributes are key correlates of PA and whether these relationships are consistent across demographic groups, settings, and locations across India.

6.2 Neighborhood Variations in Built Environment and Physical Activity

Greater land-use mix diversity in high-walkability neighborhoods indicated a concentration of non-residential land uses (restaurants, grocery or convenience stores, markets, retail, and shopping) within walking distance. Higher residential density in low-SES neighborhoods can be attributed to overcrowding of low-income affordable housing units and slum dwellings in low-SES areas in Chennai.[183] Although not significant in this study, higher residential density and land-use mix diversity have been related with walking in studies from developed countries. For example, proximity to nonresidential land uses, specifically retail uses, has been linked to higher walking rates for utilitarian purposes.[217] However, these relationships across LMICs have been inconsistent. Reasons for this may vary across LMICs. One of the reasons may be that places

with high density usually are well connected and have destinations close by because the number of people needed to support shops, services, and schools is found in a smaller area.[218] This clustering of destinations may minimize walking/ bicycling distances and individuals may not be achieving weekly recommended PA levels from utilitarian activities and shorter trips.

In the high-walkability/low-SES neighborhood, more walking/bicycling infrastructure (e.g., sidewalks, crosswalks) with high levels of travel PA suggest presence of BE supports for pedestrians may be linked to active travel. However, perception of BE infrastructure may also be subject to bias (i.e., physically active participants may be noticing more activity-friendly BE features). Notably, safety from traffic was highest in the low-walkability/low SES neighborhood, perhaps indicating lower volume and speed of traffic in these neighborhoods. Some BE differences between neighborhoods could be subtle because of geographic proximity and shared governance.

No observed difference was found between neighborhoods regarding self-reported leisure walking. There was, however, a difference between neighborhoods regarding walking for travel purposes. This difference is consistent with previous transportation research that has found no differences in leisure walking but finds significant differences in walking for travel purposes between neighborhood stratified by high- and low- walkability and SES.[41, 219-221]

When comparing the high-walkability neighborhoods, higher levels of travel PA were observed in the low-SES neighborhood. A similar pattern exists in the low-walkability neighborhoods—residents in the low-SES neighborhood engaged in approximately 126 and 61 more minutes of travel-related walking and bicycling per week respectively, than their counterparts in the high-SES neighborhood—suggesting greater active travel among lower income groups. Reasons for this may be lower levels of motor vehicle ownership among low-SES populations. For

individuals in low-SES neighborhoods that live below the poverty level in this study, walking and bicycling are likely a necessity, thus explaining their greater levels of travel PA. Participants' workplace and home may also be proximate within walking/bicycling distance to each other, boosting their travel PA. These findings are similar to those from other LMICs such as Brazil, Columbia, and Mexico. [42, 61, 222]

Contrary to usual travel PA patterns, socio-demographic variations in levels of leisure-time MVPA and LTPA across the four neighborhoods were in the opposite direction, suggesting that engagement in leisure-time MVPA was more prevalent in higher income groups. In the high-walkability neighborhoods (quadrants 1 & 3), high-SES residents reported 50 more minutes of MVPA than low-income residents. Total MVPA and all PA levels were highest among residents in the low-walkability/low-SES neighborhood, implying active lifestyles. The average resident in a low-SES neighborhood may be meeting the recommended PA guidelines of at least 150 minutes of PA per week, with travel PA being the primary contributor. In high-SES neighborhoods, leisure-time PA was the maximum contributor to total PA.

These variations in domain-specific PA can be explained by BE and socio-demographic differences across the study neighborhoods. Patterns of active travel and leisure-PA found in this study are similar to those found in other LMICs as well as in developed countries like the US. For example, studies conducted in LMICs such as Nigeria[46], Brazil[114, 115, 134, 223], Columbia[61, 224, 225], Bangladesh[2, 226], and Sri Lanka[227] have demonstrated that those living in the poorest and most disadvantaged neighborhoods tend to have higher levels of active travel, but rarely walk or bicycle for leisure and recreational purposes. In a recent study analyzing the influence of socioeconomic and BE variables on travel decisions in the US, it was found that SES influences appeared strongest.[228]

Low-income populations often confront difficult social and environmental barriers to PA and have less means to overcome them than other income groups. [182] Some of the most common barriers include: long distances to important daily destinations, lack of meaningful transportation choices, unsafe neighborhood and traffic conditions, poor access to parks and recreational facilities, air pollution, lack of time, poor health and lack of social support for exercise. While many of these barriers also exist for other income groups, they often exist to a greater degree in low-income communities. Low-SES populations may have limited time, access to resources, and BE avenues for leisure-time PA (e.g., parks, trails, etc.). Low-income populations are also less able financially to choose more activity-friendly alternatives such as: living closer to work or in a safer and cleaner neighborhood, purchasing a health club membership, paying a fee to visit the community pool or recreation center, or purchasing services that afford time for PA such as housecleaning or childcare.[221, 229] On the contrary, high-SES populations may have greater access to BE facilities conducive for PA (gyms, recreation centers, parks, etc.). For example, parks and green spaces account for 60% of overall MVPA in high income countries.[230] However, studies have shown that low-SES neighborhoods are less likely to have available facilities and locations to facilitate PA, such as parks and green spaces.[231] In most LMICs like India, parks and green spaces are being destroyed to make way for housing and infrastructure to accommodate the growing population,[120] 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

Overall, estimates of PA across leisure and travel domains are consistent with previous research in LMICs such as Nigeria[46] and Brazil[61, 224], that have shown poorer individuals tend to walk more for utilitarian purposes (e.g., going to work or shopping) and less for leisure and recreation.

In addition, low-SES populations may also have less awareness and knowledge about benefits of PA. Data from a recent study in South India underscored that an understanding of the benefits of PA may be under-developed in local populations, indicating education may be an important component of any PA policy in India.[232] Overall, results from this study highlight income inequalities in leisure PA in low-SES neighborhoods in Chennai.

Significant differences in sedentary time across neighborhoods indicated high-SES participants spent more time sitting in a week, in comparison with low-SES participants. Increased time spent in sedentary activities is known to be a risk marker for obesity in high-income populations.[233, 234] Residents of high-SES neighborhoods also had higher BMI (means=26.0 and 24.3 kg/m^2), with greater percentages of obese participants (16.5%, 15.2%). Studies in LMICs have shown high-SES populations were more likely to be obese.[235, 236] Findings of this study are consistent with previous research where high income populations have reported prolonged computer/TV use, hours of sitting at work, and sedentary travel time.[88, 235] Levels of LTPA were greater among high-SES participants, indicating their engagement in PA may be primarily occurring during structured leisure-time, while the rest of their day involved lengthy sitting times. High-SES populations are reported to be achieving WHO-recommended PA levels from leisure activities. However, the prolonged periods of sitting (8.5 hours/day) reported in this demographic group may be a potential risk factor for NCDs. Sedentary behaviors (typically in the contexts of TV viewing, computer and game-console use, workplace sitting, and time spent in automobiles) involve prolonged periods of these low levels of metabolic energy expenditure and may influence obesity and other metabolic precursors of major NCDs (type 2 diabetes, cardiovascular disease, and breast and colon cancer).[237, 238] Studies on sedentary behavior have reported that

even when adults meet PA guidelines, sitting for prolonged periods can compromise metabolic health.[239, 240]

6.3 Neighborhood Predictors of Domain-Specific Physical Activity

Results from logistic regression modeling indicate that the relationships between the BE and PA may be context-specific, and that the context in Chennai, India, differs markedly from those in high-income countries.

The positive association between residential density, land use mix-diversity, and travel PA (Model 1c) implies that dense neighborhoods and the availability of a variety of destinations can promote increases in walking, bicycling, and active commuting. 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.[169, 241]

The lack of any significant associations between residential density or land-use mix and PA types in adjusted models (model 2—adjusted for age, gender, education; model 3—adjusted for age, gender, and neighborhood quadrants) may reflect scale differences because almost all neighborhoods were dense with mixed-use. Results similar to this study were reported in Bangladesh, a neighboring LMIC.[2, 242]

This study used sample-specific definitions of high and low walkability to classify neighborhoods, but 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 the

context 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. A recent IPEN cross-country analysis demonstrated similar BE-PA associations in Bogota and Hong Kong.[28] 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.

Crime is a frequently cited barrier to PA.[243] However, its association with PA was inconsistent in this analysis. Previous studies have yielded similar inconclusive results acknowledging that the impact of perceived safety from crime on walking in residential neighborhoods needs careful examination.[243, 244] This may relate to the complexity of measuring crime (e.g., time of occurrence, people's perceptions, and coping mechanisms influence PA differently).[244]

Some BE characteristics showed stronger associations with PA in unadjusted models, but these relationships were removed in adjusted models. This suggests that levels of PA and the domains differ by socio-demographic (age, gender, education) and design variables (sampled neighborhood quadrants). Cross-sectional studies with larger sample sizes and longitudinal tracking BE changes and PA behaviors are needed to elucidate these complex relationships in LMICs.

6.4 Limitations

This study has several limitations. The cross-sectional study design limits causal inference and the relatively small sample from a single city in India may limit generalizability.[245]

Neighborhoods were selected to increase variability in walkability and SES, but this was not adjusted for in all statistical models. There remains the possibility of residual confounding. Self-reported PA and neighborhood measures are subject to bias (e.g., overestimation of PA; social

desirability of PA; physically active people may notice more BE infrastructure and neighborhood destinations).[62] Duration of PA is based on self-report, prone to recall bias, and likely over estimates rates of PA.[98] A limitation of this study and PA literature in general is a lack of consensus on measuring domain-specific PA in LMICs (e.g., lack of tested items, inadequate details on types of PA).[89, 98] IPAQ-LF modules to capture leisure and travel PA have not been validated in India.

Snowball selection was used to recruit participants within the neighborhoods in this study, but the demographic differences between the neighborhoods may limit generalizability.[109, 246] The cross-sectional design does not allow us to determine whether neighborhood design caused PA differences or whether individuals self-select into neighborhoods according to PA opportunities, including walkability. Assessment of residential choice and psychosocial correlates of PA need to be included in future PA environmental research.[150] This study was conceived as a pilot investigation, and the restriction to small samples in four neighborhoods in one city means that neighborhood comparisons of PA and BMI should be considered preliminary. The sample size is also a limitation for subgroup analyses and interactions. Measurement of neighborhood food environments also could significantly augment the understanding of the relation between environment and weight status.[247] Our results indicate a need for larger and more definitive studies of hypotheses regarding the effects of neighborhood design on PA, BMI, and other health variables.

As a result of mechanization and urbanization, PA in high income countries has become structured and mostly occurring during leisure-time in environments (e.g., parks, recreation centers, and gymnasiums) designed for it.[248] In contrast, PA among LMIC populations is unstructured and occurs as a part of everyday life. Physically intensive activities may be

intersecting domestic, occupational, and travel domains in the daily routines of LMIC populations, making it difficult to disentangle independent effects. For example, activities requiring energy expenditure at home (cleaning, gardening), at work (farming, physically demanding labor), and when traveling (walking, bicycling), are often mixed in everyday lifestyle of LMIC populations. In addition, differences in culture and social context of everyday life (e.g., social stigmas attached to walking, use of the car as a social status symbol, attitudes towards women in public spaces, etc.) may impact levels of utilitarian PA (e.g., walking or bicycling to work, school), and may not be adequately captured by IPAQ-LF domains.

Household PA was not measured in this study, which is another limitation. Household PA in some LMICs like India in divided along gender lines, and may be significant contributor to total PA, particularly among housewives and the unemployed.[249] The traditional role of women in assuming responsibility for a majority of the household work, as caregivers, and supporting other members of the households, may limit the amount of time available for leisure PA activities.[2] Cultural expectations, beliefs, and norms may also restrict the participation of women in certain forms of PA among some religious and ethnic groups in the study region.[249] Expanding the definition of PA to include household and occupational activities, in addition to the leisure and travel domains, as well as an understanding of where these PA types occur, is necessary to gain a complete understanding of BE-PA relationships in India. Although exercise is promoted in public health campaigns to increase the overall PA levels of a population, it is important to understand socio-economic factors, external motivators and social context of everyday life in India in order to develop and deliver effective PA interventions.

6.5 Strengths and Implications

Although this study was based on relatively small samples at the neighborhood level, it may be the first to measure and document BE features and PA levels in India. This project advances the current state of urban planning and public health research by identifying neighborhood-level differences in BE characteristics, domain-specific PA, and weight status in urban India. As part of IPEN, state-of-the-art methods, measures, and instruments were used.[250] 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 other LMICs. Differences in domain-specific PA in India suggest that measuring only leisure-time PA, as most studies in the developed countries have done, may underestimate levels of total PA in LMICs. This necessitates examination of all-domain PA (household, occupational, travel, and leisure) and relationships with BE in LMICs. It is important that future studies develop neighborhood walkability and PA measures unique to India based on empirical analysis. 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[251] 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 about environmental design policies and physical infrastructure likely to support and encourage healthy, active lifestyles in India. Findings are being actively disseminated to local policy makers, public health practitioners, and urban planners to accelerate the translation of research evidence into policy and practice.

Chapter 7: Implications for Policy and Practice

Research on the BE and PA has experienced tremendous increase during the past 20 years.[34, 37, 116, 252] These studies have been of great benefit to the field by informing public health and urban design policy and practice.[109, 252-256] Despite this, PA levels have been on a steady decline among populations of all age groups across the world. Various studies have reported that adults and children in the US and in other industrialized nations do not meet health-related guidelines for PA. Similar disturbing trends are also being observed in LMICs across the world where physical inactivity is considered an emerging public health problem.[257] With increasing evidence of the detrimental effects of physical inactivity and sedentary behaviors, there is interest in enhancing research on policies that may influence PA in both developed and developing countries. Furthermore, it is essential that PA interventions be conceptualized on a population basis, because intervening with individuals or small groups is unlikely to bring about population-wide change.[140] Implications are particularly marked in LMICs where the burden of NCDs is high and rising and a significantly large proportion of people are at-risk for chronic health conditions.

7.1 Gaps in Research and Policy Implementation in LMICs

A systematic policy review by Lachat et al. (2013) highlighted substantial gaps between policy development and implementation of strategies for prevention of NCDs in LMICs. In this review, although NCD policy strategies were found for 47% of LMICs, specific actions to promote PA were present in only a minority. It is notable that the lack of policies is in direct contradiction to a specific global commitment and endorsement of the Global Strategy on Diet, Physical Activity and Health made at the 2004 World Health Assembly to address NCDs.[154] A decade later, despite further voluntary declarations to act on the avoidable burden of NCDs, their study revealed that disappointingly little has changed. Despite some policy statements, there remains

virtually no development of specific policies and programs to address NCDs in LMICs facing the highest rates of premature morbidity and mortality.[65]

In a review of published evaluations of environmental and policy interventions to increase PA, Sallis and colleagues (1998) highlighted the potential of large-scale environmental and policy interventions to influence entire population behaviors. Cross-sectional data from studies in the last decade has also indicated that environmental and policy variables are associated with PA behaviors of children, adults, and the elderly.[258] However, the lack of research and translation to policy is clearly evident in the area of PA promotion in LMICs. Further, the application of ecological models and conceptual frameworks for active living (outlined in Chapter 3) are indispensable to PA promotion because behavior must be done in specific physical settings that support and encourage PA.[18]

Physical activity is a multifaceted, complex behavior. Prior research has identified micro-level environmental correlates of PA (land use, street connectivity, density, aesthetics etc.) in developed countries, but there remain large gaps in this research for LMIC contexts. The planning and policy processes that result in such attributes have also been largely overlooked in LMICS. Policies set forth by land use and transportation plans have the potential to influence leisure and travel PA, but there is limited empirical evidence about the extent to which specific land use policies complement non-motorized transport infrastructure improvements to promote active commuting and leisure PA in LMICs.[259, 260]

It is time for policymakers and practitioners to shift to designing communities that intentionally facilitate health and well-being. To effect this change, researchers have acknowledged the need to plan creatively for healthy communities. The first step is to understand better the elements of the BE that promote health, particularly in LMIC contexts. From the research to date, the public

health and design community is aware that some BEs encourage walking, biking, and social interaction more than others do.[33] But overall, there is still much to learn about the effects of the BE on health, particularly in LMICs. Currently used methodologies and the use of small, local samples limit PA surveillance, external validity, and dissemination of many results, interventions, and policies.[261]

7.2 Implications for India

India's epidemic of NCDs has already passed its early stages; the demographic and epidemiological transitions that are in progress have important implications for individuals, families, communities, and the nation as a whole.[65] In comparison with developed countries, the development of a national policy program to address NCDs in India has been slow and recent. Several economic and public policy reforms over the last decade in India have bolstered its healthcare system and policies. Since 2008, India has made substantial progress in development of national policies that are backed by adequate resources to comprehensively address the burden of NCDs.[5, 8, 10] However, most of these national programs have been structured around a technological response and focused on specific target rather than having multicomponent interventions, and their success has been variable.[12] Policy makers and practitioners have strongly advocated the need to strengthen the social and policy frameworks to enable the scale up of NCD preventive interventions.[76, 120, 262-264]

Despite the substantial burden of NCDs in India, data from the World Health Survey show that a large proportion of the population receives no treatment for NCDs (e.g., only 47.2% of patients with diabetes receive treatment).[154, 265] Rural and economically disadvantaged populations have poor health outcomes; individuals in the poorer quartiles are between two and 20 times less likely to receive any treatment than are those in the richer quartiles.[12] There have been urgent

calls from researchers and medical practitioners to create an agenda for NCD prevention and control that should be a political priority and central to the national consciousness of India. Several barriers to policy development and implementation exist. The effect of macroeconomic policies on NCDs has not been assessed. For example, in India's rush to build roads for the rich who can afford cars, the needs of pedestrians and bicyclists have been ignored, placing hundreds of millions of people at risk of injury.[50, 51] The introduction of new and cheap motor vehicles and the reduction of import duties on automobiles might exacerbate the NCDs. Second, little progress has been made in the development of policies to improve public transport and urban design to increase the opportunities for bicycling and walking. Third, approaches to NCD prevention and control are vertical, do not acknowledge the need for intersectoral or transdisciplinary action, and do not address the overlap that is necessary between multiple disciplines and public health programs to tackle NCDs.[265]

Urban areas in India are growing rapidly in population.[59, 120, 185, 188] According to a survey by UN State of the World Population report, 40.76% of India's population is expected to reside in urban areas by 2030.[266] As India becomes more urban, the impact of the BE on PA, sedentary behaviors, and weight status should be assessed. An understanding of BE correlates of primary PA domains (transport, leisure) can support the development of contextually tailored interventions and policies to reverse the determinants of inactivity occurring through patterns of urbanization and sedentary behaviors in India. Initiatives to reduce NCD risk among residents living in neighborhoods of differing income and walkability should include a focus on reducing TV viewing time and other sedentary behaviors and enacting policies that can lead to the development or redevelopment of more-walkable neighborhoods. Additional research is needed to advance measurement and evaluation of BE's and PA in India.

7.3 Next Steps and Directions for Future Research

Priority areas for future work in the BE-PA area include, but are not limited to, enhancing transdisciplinary collaborations, measure development, intervention research, raising the priority of policy evaluation, emphasizing dissemination of findings, and research translation.[260] Key recommendations for future research in LMIC contexts are briefly discussed in the sections that follow.

7.3.1 Transdisciplinary Problem-Solving and Collaborations

The complexity of public health problems today presents a challenging scenario. Understanding and designing solutions for these problems requires perspectives from multiple disciplines and fields as well as cross-disciplinary research and practice teams.[267, 268] PA behaviors like walking are influenced by multiple factors, ranging from the individual level (e.g., beliefs, attitudes, etc.) to broader dimensions of the socio-ecological system (e.g., environment, community, culture, policy).[18] From a theoretical perspective, a variety of studies have focused on public health theories that influence PA. However, concepts from allied disciplines have not been reviewed. Eyler et al. (2010) suggested that significant, if not some of the biggest, improvements in rates of PA are likely to come from sectors outside of health (e.g., transportation, urban planning, parks and recreation). The complex interplay and wide-ranging impact of these factors at all levels necessitates synthesis of information from several established disciplines or traditional fields of study. It is therefore crucial for the public health profession to undertake a transdisciplinary approach and reengage with other professions.

Transdisciplinary research is an approach that integrates disciplines, as well as researchers and practitioners, and requires close collaboration between people in professions who do not necessarily share common academic homes (departments), language, concepts, and methods.

This approach offers an understanding of interactions among the biological, behavioral, social, and public health sciences; shared disciplinary frameworks in analyzing health problems; and the integration and evaluation of transdisciplinary solutions to alleviate complex public health issues.[268, 269] To address the multitude of questions, public health professionals should work closely with experts in other fields (e.g., architects, planners, policymakers, social scientists, traffic engineers, developers, law enforcement officers, economists, social marketers). Such transdisciplinary research projects can provide valuable opportunities to collaborate on interventions to improve the health and well-being of both individuals and communities, and enable translation of these evidence-based interventions into policy approaches. Operationalizing this concept requires expanding our understanding of how policies in other sectors influence PA and health.

7.3.2 Development of Measures with Relevance to LMIC Populations and Settings

It is not clear the extent to which the existing BE measures are sensitive to the needs of LMIC population groups and settings. It is likely that PA barriers and facilitators vary by age, physical abilities, and culture across LMICs. The lack of relevance of existing measures to rural environments has been acknowledged, and environmental attributes may have different meanings in LMICs versus high-income countries and in youth versus adults.[24]

It is important to ensure that BE measures are relevant to populations at highest risk of inactive lifestyles and resulting diseases, such as low-income, racial/ethnic minority, older adult, and rural populations. However, it may not be possible for any single measure to be optimal across LMICs or a subgroup population of interest in LMICs. Thus, use of core measures with adaptations for specific target populations in LMICs may be a pragmatic solution.[65] Systematic community input is necessary to develop or adapt measures that are appropriate for the

population.[170] An important limitation is that most evaluations of measurement properties are often conducted in one region, so there is the possibility that limited variability in BE variables could reduce reliability and validity coefficients. Census tracts have been used previously to define neighborhoods in studies examining BE-PA correlates,[247, 270] but the defined area of an individual's environment for PA is unknown, as is whether individuals are influenced by the environmental characteristics of entire neighborhoods or by the specific areas around residences.[190, 246]

It will be important for future studies to include socio-cultural variables in addition to the measures of the BE. More systematic attention to measuring social and cultural environments in LMIC contexts could lead to improved understanding of their role in enhancing or inhibiting PA. Analyses that include variables from multiple levels of ecological models are expected to be more powerful in explaining human behavior.[143, 271, 272] Principles from ecological models predict interactions across levels, such that BE attributes may operate differently in various social contexts.[24] Testing such hypotheses requires adequate measurement of both social, cultural, and BE variables.

In contrast to the rapid development of BE measures in developed countries, there is a void in development and validation of measures for LMICs. To the study investigators knowledge, there are no measures designed to assess neighborhood BE characteristics in India. There are no surveys designed to provide detailed assessments of active transportation or recreational BEs, like parks and trails, which are expected to support recreational PA. In addition, published measures of policies that govern BEs are also lacking. This policy-relevant information is a clear research need, because valid measures of the policy determinants of BE and PA have direct relevance for public health planning and evaluation in LMICs. Future research needs to evaluate

more neighborhood environment variables and the relation between objective measures of environment and perceived BE measures to identify parsimonious, yet accurate, assessments of neighborhood BEs in India and other LMICs.

7.3.3 Intervention Research Featuring Natural Experiments

Although a number of environmental and policy interventions to promote PA are being implemented widely across developed nations, there is sparse systematic information on the most effective approaches to guide population-wide interventions. The traditional approach to NCD prevention through awareness creation, one-on-one education (e.g, PA counseling) and modifying individuals' behavior has met with very limited success. Strategies and interventions aimed at changing individuals' behavior have been ineffective in creating population-wide changes in PA levels. It is widely accepted that the environmental context drives individual lifestyle and that programs need to incorporate environmental determinants (i.e., the role of the BE for PA) in order to be effective.[273]

Rapid socioeconomic growth in many LMICs, alongside and growing migration and urbanization are generating "natural experiments" that will allow investigation of the upstream determinants of common risk factors for NCDs.[274] In order to understand the upstream causes of NCDs, researchers in LMICs can make use of natural experiments such as the introduction of urban mass transport systems on PA[275, 276]; social and economic change on risk factors[277]; and rural development strategies (e.g., new roads, employment schemes) on obesity and diabetes. Using a combination of natural experiments and existing methods to monitor and evaluate changes in community health outcomes can help to demonstrate a positive cost-benefit ratio of policies being implemented, thus raising the priority of policy evaluation.

7.3.4 Surveillance and Monitoring of Physical Activity and Sedentary Behavior

The population burden of many NCDs in LMICs is not known. Recent global burden of disease studies have produced modeled estimates derived from existing, but patchy, data of common risk factors trends to fill the information gap.[278-281] Existing surveillance and monitoring systems require expanding to include the major NCDs and risk factors to improve estimates of burden and monitor trends in LMICs. There is a need for large-scale, evidence- informed surveillance of PA. This is extremely crucial in the context of LMICs, where the disease burden of obesity and NCDs is approaching pandemic proportions.

The physical, economic, and social environments in which humans sit or move within the contexts of their daily lives have been changing rapidly in LMICs. As NCDs becomes more prevalent in LMICs, and populations become more urban, it is important that future studies understand energy expenditure patterns, sedentary behavior, and their relationship to neighborhood BE characteristics. In most LMICs including India, people generally adopt PA as part of their work and travel needs rather than as part of leisure-time activity.[282] Modernization and a gradual shift towards a sedentary lifestyle have inevitably resulted in a progressive decline in work-related PA in LMICs. Sedentary behaviors (typically in the contexts of TV viewing, computer and game-console use, workplace sitting, and time spent in automobiles) have emerged as a new focus for research on PA and health, but there is limited evidence from LMIC contexts.[237]

Saelens at al. (2003) suggest that a 70-minute-per-week difference in PA translates to walking 3 miles more per week given an approximate 20-minute-per-mile pace. Over the course of a year, this amount of walking would yield about 15000 kilocalories of energy expenditure for a 68-kilogram person, which, if not offset by caloric intake, could result in almost 1.8 kilograms of

weight loss. Research shows that even when adults meet PA guidelines, sitting for prolonged periods can compromise metabolic health. TV time and objective-measurement studies show deleterious associations, and breaking up sedentary time is beneficial.[233, 237, 238] Sitting time, TV time, and time sitting in automobiles increase premature mortality risk.[240, 283-285]

Prolonged sedentary behaviors are known to mediate relationships between neighborhood walkability and overweight/obesity.[233] There are several lines of evidence for a relationship between sedentary behavior and health, including epidemiological investigations of sedentary behavior and mortality or risk of chronic disease[286], but little is known about these relationships in LMICs. Further evidence from prospective studies, intervention trials, and population-based behavioral studies is required in LMICs. Future research could examine how these prevalent and often prolonged sedentary behaviors mediate relationships between neighborhood walkability and NCDs in LMICs.

7.3.5 Policy Development and Evaluation

Public health has a long history of addressing important challenges through regulatory and policy mechanisms. Predicted long-term outcomes of the NCD epidemic include a decline in population health because of disease and disability along with a substantial peak in societal and economic costs. In response to this increasing prevalence, there is a focus on identifying effective strategies to reverse trends. These strategies include policy and environmental changes that are designed to provide opportunities, support, and cues to help people develop healthier behaviors.[260] Changes in policy can help foster and maintain individual-level behavior change, compared to interventions focused solely on individual-level health changes that are overall minimally effective and can be costly. Emerging evidence shows that policy and environmental approaches can lead to changes in health and health behaviors of populations that are more sustainable than

intervention approaches.[258] In contrast to interventions focused on individuals, policies have the potential to affect health across populations.

Abundant opportunities to evaluate policy processes and impacts on health, quality of life, and PA behaviors have been provided by recent innovative approaches to community design, transportation policy, climate change, social development and social equity at the city, state, national, and global levels.[260] Some of these innovations such as urban growth boundaries in the US,[287] urban design in Curitiba, Brazil,[114] and reclaiming public space in Bogota, Colombia,[224] have been evaluated. Many other promising strategies such as congestion pricing in London, climate change policies in New York, and the implementation of bus rapid transit and light rail systems in many LMICs remain to be evaluated for their impact on PA health.

LMICs urgently need to scale up interventions and develop integrated policies that address various risk factors for NCD prevention through multi-stakeholder collaboration and cross-sector involvement.[65] Clear, prioritized actions integrating the public and private sector are needed to harness the NCD epidemic. Documentation of such actions in policy documents that are publicly available is important to share lessons learned, promote engagement with the stakeholders, and stimulate accountability and leadership in the fight against the burden of NCDs in LMICs. Researchers and practitioners have suggested that the establishment of an open-access and publicly accessible database of policy documents with regular systematic reviews of policy development might prove to be an incentive in this regard.[258, 260] In LMICs, not only is research on the impact of the BE on PA necessary, but establishment, implementation, and monitoring of BE policies and subsequent impacts on PA is crucial for public health.

7.3.6 Integrating Research, Policy, and Practice

Public health has several health priorities that require thoughtful and careful collaborations between researchers, practitioners, and policymakers across many sectors.[288, 289] The most pressing fact is that we have an NCD epidemic caused by environments and policies that encourage over-consuming and under-expending energy. The urgency of addressing this epidemic compels a variety of policy-related actions that reach far and deep within the population. To maximize impact, these actions must be feasible, synergistic, cost-effective, free of unintended adverse consequences, and based on the best available research evidence.[230]

In a commentary on integrating research, policy, and practice to achieve changes across sectors, Economos et al. (2013) discussed the role of researchers as 'evidence generators' and policy makers or practitioners as 'evidence users'. To address the perspectives and challenges faced of these entities, the Institute of Medicine's 'Bridging the Evidence Gap' report explains how various forms of evidence are used in evidence-based public health decision making. A closer look at the types of evidence and how it's used in policymaking illustrates the range of information often taken into account by policymakers and suggests an expanded role for evidence generators. For example, researchers suggest that when conducting a controlled trial or intervention in a community with multilevel outcomes, it is important to pay attention to the knowledge, ideas and interests, and opinions and views of the community as well as costs and resources used. A variety of distinct pieces of evidence (quantitative and qualitative) that emerge from a study and sources of knowledge have meaning and can ultimately inform policy.[140, 290] This process makes the results more meaningful for the community and their representatives. Different types of evidence can be merged with specific capacities, such as an individual's skills, experience, and participation in networks, to influence the adoption and adaptation of evidence

in practice.[260] At the organizational levels, capacity is often visible leadership, partnerships, the development of appropriate workforce and organizational structures, and the ability to mobilize and allocate resources. Key at a system level are the processes, policies, politics, and people.[288] With many forms of evidence to draw from, a range of policies can be implemented to address a particular topic, increasing the likelihood for impact by leveraging, enabling, and amplifying efforts. For example, focused initiatives that promote active travel planning can be enabled by the provision of cycle lanes and amplified by introducing congestion pricing.[291]

In summary, timely and credible evidence is needed to help decision makers at all levels decide what to do and how to do it. We should all consider context, relevance, participation, and external validity as studies are designed and hypotheses are tested that will build the evidence base and help inform policy development and practice in LMICs.

7.3.7 Research Translation and Dissemination of Findings

National and international organizations recommend creation of environments that support PA where people live, work, play, study, and travel.[267] To identify effective policy approaches for promoting PA, researchers have examined the relation between community design variables and walking or cycling for transportation. A challenge to public health practice and policy is how to translate these science-based interventions into actions that will improve health (e.g., revised zoning, building codes, infrastructure improvements).[292, 293] A range of policy issues relevant to the promotion of PA largely derive from research in urban planning and travel behavior. For effective interventions to reach their potential (i.e., evidence-based policy), they need to be applied at various policy loci within a governmental structure (e.g., national, state, city).[294, 295] Despite the importance of policy enactment in PA promotion efforts, communication between public health researchers and policy makers has been largely lacking.[296]

Planning and development of communities is multifaceted. Land use decisions are typically made at the local level but are often impacted by a complex combination of government regulation, transportation investments, development focused incentives and policies, and volatile market forces.[297] Therefore, land use decisions that increase the supply of homes in settings that support active living require the engagement of seemingly disparate sectors. This level of multisectoral engagement requires institutional change and should involve all levels of the ecological model to address individuals, social environments, physical environments, and policies. Routine and informed interactions among health, environmental, land use, and transportation officials, as well as across public and private sectors is likely to be a key component in increasing the supply of activity-friendly communities.[298]

The current scientific evidence and international experience in the fight against NCDs consistently indicates the need for comprehensive and integrated action on various risk factors. Mobilization of the main actors—in particular, governments, international agencies, the private sector, civil society, health professionals, policy makers, and individuals—is imperative for the translation and dissemination of research.[299] Policy changes can lead to activity-supportive environments and incentives. Research on environmental and policy influences on PA is well underway in many countries. An important use of the research is to inform policy debates, but the translation of research to policy and subsequent implementation is an emerging science.[267]

7.4 Conclusion

While this study is first-generation research in India, findings from this study 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.

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. Transdisciplinary collaboration and dialogue between researchers, practitioners, 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.

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Appendix

Appendix 1. Qualitative Interview: Research Information Sheet.

Understanding Your Participation
Active Travel Patterns - Chennai Survey

We invite you to participate in a research study being conducted by investigators from Washington University in St. Louis, MO, USA. The purpose of the study is to assess walking, bicycling, and transit use in the city of Chennai, India. Your contribution will help us make recommendations to the city council on how to improve pedestrian and transit infrastructure in the city.

If you agree to participate, we would like to conduct a 30-45 minute audio-recorded interview at a time and place convenient to you. You are free to skip any questions that you prefer not to answer. We would like to contact you with follow-up questions after 12-18 months. However, if you do not wish to be contacted, please let us know and we will not contact you for follow up.

We will not collect your name or any identifying information about you during the interview. Your name and contact information will be stored separately in an encrypted file or hard drive and will be transferred to a secure server at Washington University in St. Louis with only research team access. When we write a report or publish any results from this study, we will do so in a way that you cannot be identified.

Your participation in this study is completely voluntary. You may decline to participate or terminate the interview at any time.

There are no known risks from being in this study, and you will not benefit personally. However, we hope that results from this study will help us draw the Chennai city council's attention to citizens' commuting choices and reasons that deter or encourage walking, bicycling, and public use of mass transit in Chennai.

If you have any questions about the research study or have information to add after the interview, please call Deepti Adlakha at +91 (044) 42649494 (Chennai) or 1 (314) 935-0158 (United States) or email deeptia@wustl.edu.

If you have questions about your rights as a research participant, please contact the Human Research Protection Office, 660 S. Euclid Ave., Campus Box 8089, Washington University St. Louis, Saint Louis, MO 63110, (314) 633-7400, or 1-(800)-438-0445 or email hrpo@wusm.wustl.edu.

Thank you very much for your consideration of this research study.

Appendix 2. Residents Interview Guide.

Introduction: Thank you for agreeing to participate in this interview. We will be talking with residents across the city to identify issues related to walking, bicycling, and public transport. The interview will take about 30 minutes.

When we talk about home neighborhood, we mean the area around where you live. When we talk about workplace neighborhood, we mean the area around where you work.

1. Think about where you live. Can you describe the physical sights and surroundings in your home neighborhood?
   (Prompts: apartments, residences, condos, gated communities, school, etc.)

2. Do you work? (If "no", proceed to Q. 3. If "yes", continue) Can you describe the physical sights and surroundings in your workplace neighborhood?
   (Prompts: commercial, business, shopping, restaurants, 1-3 storey buildings, 4-6 storey, high rise buildings)

3. What are some of the stores, businesses, and facilities in your home and/ or workplace neighborhoods? (Prompts: supermarket, fruit/ vegetable market, corner store, library, school, pharmacy, fast food, restaurants, place of worship like temple, mosque, church**)**

4. Think about the local places you regularly travel to. Can you describe your commute to these places; for example, commute to work, to shop, to a nearby park, for errands?
   (Prompts: workplace, school, errands, shopping, parks, place of worship, walk, bike, public transport)

5. Are there specific times of the day when you commute to these places? How long do you spend commuting to each of these places?

6. What modes of transport do you use while commuting? Does any portion of your commute include walking, for example, walking to a bus stop, train station?
   (Prompts: walk, bicycle, car, bus, suburban train, a combination of these modes)

7. Do you have good and bad commute days? What makes a good commute? What makes a bad commute? How does this vary by time of day?
   (Prompts: good - little traffic, fair weather, bad - traffic accidents, rain)

8. How often do you walk/ bicycle in your home or workplace neighborhood?
   (Prompts: everyday, few times every day, few times during a week)

9. Can you name some of the places you walk/ bicycle to in your home neighborhood? How often to you walk/ bicycle to these places?
   (Prompts: convenience store, supermarket, street vendor, restaurant, park, place of worship)

10. How easy or difficult is it to get to places near your home?

11. Do you walk/ bicycle alone or with someone?

12. Can you name some of the places you would like to walk/ bicycle to in your home neighborhood?
    (Prompts: convenience store, supermarket, street vendor, restaurant, park, place of worship)

13. Can you describe the street and sidewalk conditions in your home and/or work neighborhood?
    (Prompts: crosswalks, obstructions, trees, shade, safety, traffic)

14. How long have you lived and worked in these neighborhoods? Have you noticed any changes in street and sidewalk conditions over the last few years?
    (Prompts: traffic, noise, air pollution, obstructions, no sidewalks)

15. When did you move to your current residential address? Did you consider street, sidewalk, commuting preferences, or any other neighborhood characteristics when selecting your current home location?

16. What are some of the challenges/ obstacles you encounter when you walk/ bicycle/ commute?
    (Prompts: congestion, damaged sidewalks, trash, illegally parked cars and motorbikes, vendors, road signs, construction debris)

17. What are some of the traffic hazards you face in your home and/ or work neighborhoods?
    (Prompts: crowding, congestion, traffic speed, unregulated parking)

18. How do you address these challenges and hazards?

19. What are some of the safety issues you encounter when you walk/ bicycle in your home and/or work neighborhood?

20. Do you see your neighbors/ other people walking in your home or work neighborhood? If yes, at what times of the day?

21. Have you or any other neighborhood residents communicated with the city government officials about these issues?

22. What improvements of pedestrian infrastructure are necessary in your home and/or work neighborhood?

23. What do you think the city government can do to improve walkability?

24. Do you have ideas for city-community partnerships to improve walkability?

25. Are you aware of any efforts to improve walkability in Chennai?
    (Prompts: The Hindu's Right to Walk campaign, Transparent Chennai initiatives)

26. Is there anything else you would like to add to this discussion?

Would you be willing to participate in a follow up interview after 12-18 months? If you do not wish to be contacted, please let us know and we will not contact you for follow up.

Appendix 3. Key Informants Interview Guide.

Introduction: Thank you for agreeing to participate in this interview. We will be talking with local officials and representatives across the city to identify issues related to walking, bicycling, and public transport in Chennai. This interview will take about 30 minutes.

1. Please tell me about yourself and your department/ organization.
   (Prompts: Mission/ Aims? How long in the area? Services provided? How do you define your organization/community/service area?)

2. What are some of the new developments with respect to walking, bicycling, and public transport infrastructure in Chennai? Are there any that your department/ organization is involved with?

3. Who is the lead planning entity of these developments?

4. What is considered in the planning of these developments? What are your department/ organization's roles and responsibilities with respect to these developments?

5. Is health, physical activity, or pedestrian safety discussed when planning these developments? (If no, ask what is discussed?)

6. What is the primary source of funding for these developments?

7. Is community input considered when planning these developments? What is the level of community involvement? (If minimal or no community involvement, ask what are the barriers to involvement?)

8. How do neighborhood residents communicate with your department/ organization about issues regarding walking/ bicycling/ public transport infrastructure?

9. What do you think could encourage and support more community involvement/advocacy around these issues?

10. What improvements of walking/ bicycling/ public transport infrastructure are necessary in Chennai? What is being done by your department/ organization to address this?

11. What are some of the issues/challenges that your department/ organization face?
    (Prompts: complexity of issue, lack of information, inadequate staffing?)

12. How do you address these challenges?

13. Do you have ideas or suggestions for city-community partnerships to improve walking, bicycling, and public transport infrastructure?

14. Are there other people you think we should talk to? Have we covered everything you think is important? Is there anything else you would like to add to this discussion?

Would you be willing to participate in a follow up interview after 12-18 months? If you do not wish to be contacted, please let us know and we will not contact you for follow up.

Thank you for taking the time to talk with me. We will be sending out a summary of results to everyone at the end of the study.