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Exploring associations between perceived and objective measures of the built environment and physical activity in Mexican adults living in the city of Cuernavaca.

T H E S I S

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To Nelson, Julia and Eugenia

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Overview

Given that physical inactivity and non-communicable diseases are global leading causes of death, it is important to identify new ways for increasing physical activity. Changing the physical form of the community, or built environment, in a way that is more activity-conducive is a promising strategy to produce population increases in physical activity. Compelling evidence from high income countries (mainly the U.S. and Australia) has linked specific features of the built environment with more physical activity. However, evidence from Latin-American countries suggest differences from what is known for high income countries. This study proposes to extend knowledge on the environmental characteristics that may be relevant for physical activity promotion in a Mexican setting.

This dissertation presents the results of four years of work, which included three secondary data analyses using data from the Mexican site of the International Physical Activity Environment Network Study (IPEN) Adult project. The IPEN Adult project explores built environment and physical activity relationships among 12 culturally diverse countries, including Mexico. The Mexican site of the IPEN project was based in Cuernavaca, México. Data were collected in 2011 and were analyzed initially in 2012 and 2013, as part of the thesis dissertation of Dr. Deborah Salvo.

This dissertation takes upon results observed by Dr. Salvo between objectively measured features of the built environment and physical activity, and expands the current knowledge by exploring the relationships between perceptions of the built environment and physical activity, as well as objective and perceived measures of the built environment, using the data collected for the study in Cuernavaca, Mexico. The background and the three manuscripts presenting the results of the analyses are presented in this dissertation. Considering the results of the three analyses, a final discussion, directions for future research, and policy implications are provided in the final section of this dissertation.

Abstract

Physical inactivity accounts for 5.3 million deaths per year globally. In México physical inactivity prevalence among adults increased 27% over the past six years; currently more than 30% of the population is physically inactive. Specific features of the built environment (BE) have been linked with more physical activity in high income countries. However, preliminary evidence from Mexico suggest differences from what is known for these settings, which might be driven by the way the BE is perceived. The aims of this dissertation were: 1) To estimate the associations between perceived measures of the BE and objectively measured moderate to vigorous physical activity, and self-reported walking for transport and leisure-time PA. 2) To estimate the associations between objective (500 m buffer) and perceived measures of the BE. 3) To test if the relationship between objective (500m buffer) and perceived measures of the built environment is moderated by demographic variables, such as age, sex, socioeconomic status and marital status, using data collected from a sample of Mexican adults. A secondary data analysis was conducted using data from the Mexican site of the International Physical Activity Environment Network Study (IPEN) Adult project. The original study is a cross sectional study which collected data for a representative sample of adults (n=677) living in Cuernavaca. Physical activity was measured objectively (accelerometry) and subjectively (International Physical Activity Questionnaire). Features of the built environment were measured objectively (using Geographic Information Systems) and by self-report (using the Abbreviated Neighborhood Environment Walkability Scale). Our results showed that some perceived environmental features are associated with objective and self-reported physical activity, however, patterns of association differ from those reported in high-income countries. Among the main findings, we saw that perceived aesthetics, park availability, crime safety and proximity to transit stops were relevant environmental features for physical activity. However, other variables that have been consistently related with physical activity in high income countries (e.g. land use mix diversity, residential density and connectivity) were not. Our findings highlight the relevance of contextual factors when studying physical activity and suggest the need to redefine concepts like walkability and activity-friendliness based on context.

Resumen

La inactividad física es responsable de 5.3 millones de muertes al año en el mundo. En México, la prevalencia de inactividad física aumentó 27% de 2006 a 2012, de manera que en la actualidad más del 30% de la población no realiza actividad física suficiente. Ciertas características del ambiente construido han sido relacionadas con más actividad física en países de ingresos altos. Sin embargo, la evidencia preliminar en México sugieren diferencias de lo que se ha reportado en estos lugares, las cuales podrían deberse a la forma en que el ambiente construido se percibe (ambiente percibido). Los objetivos de esta tesis fueron: 1) Estimar las asociaciones entre el ambiente percibido y mediciones objetivas de actividad física moderada a vigorosa, así como actividad física auto-reportada de transporte y recreativa; 2) Estimar las asociaciones entre mediciones objetivas (radio de 500 m) y percibidas del ambiente construido, y 3)Explorar si las relaciones entre las mediciones objetivas y percibidas del ambiente construido están moderadas por variables demográficas como edad, sexo, nivel socioeconómico o estado marital, utilizando datos recolectados en una muestra representativa de adultos Mexicanos (N=677, 20-65 años) que viven en la ciudad de Cuernavaca. Se realizó un análisis secundario de datos provenientes del sitio mexicano del "International Physical Activity Environment Network Study (IPEN)". El estudio original es un estudio transversal. Los datos fueron recolectados en una muestra representativa de adultos que vivían en Cuernavaca. La actividad física se midió utilizando mediciones objetivas (con acelerometría) y auto-reportadas (con el Cuestionario Internacional de Actividad Física, IPAQ por sus siglas en inglés). Las características del ambiente construido se midieron de manera objetiva (utilizando sistemas de Información Geográfica) y por auto-reporte (con la Escala Corta de la Caminabilidad del Ambiente de la Colonia). Nuestros resultados muestran que aunque algunas características del ambiente percibido están asociadas con la actividad física medida de manera objetiva y auto-reportada, los patrones de asociación difieren de los observados en países de ingresos altos. Entre los principales resultados se encuentra que la estética, disponibilidad de parques, seguridad del crimen y la proximidad a las paradas de rutas son características importantes para la actividad física. Sin embargo, no se observaron relaciones entre la actividad física y otras variables que han sido asociadas de manera consistente con mayor actividad física en países de ingresos altos (por ejemplo diversidad de uso de suelo, densidad residencial y conectividad). Nuestros resultados subrayan la importancia de los factores del contexto al estudiar la actividad física y sugieren la necesidad de redefinir conceptos como el de "caminabilidad" o "amigable para la actividad física" en base a las características del contexto.

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Part I. Background

I.I. Introduction

Physical inactivity has been estimated to account for more than 5.3 million of the 57 million deaths that occurred globally in 2008, comparable to the number of deaths attributed to smoking (1). Deaths attributed to physical inactivity are largely due to four major diseases: heart disease, Type 2 diabetes, breast cancer and colon cancer (1, 2). Therefore, physical inactivity has a major health effect worldwide and the reduction or elimination of this unhealthy behavior could improve health considerably. In Mexico the leading causes of death are Type 2 diabetes and cardiovascular diseases, and seven out of ten adults are either overweight or obese. Furthermore, physical inactivity prevalence among adults has increased 27% over the past six years; currently more than 30% of the population is physically inactive (3).

In order to increase population levels of physical activity, it is important to understand the underlying causes for (in) activity. The ecologic model proposes that individual, interpersonal and environmental factors have an influence upon physical activity (4). Recent research has also focused on the role of the built environment (BE) and its influence on physical activity, and suggests that population-level increases in physical activity may be more effectively achieved through strategies that target the BE. There is compelling evidence linking specific features of the BE with physical activity. Characteristics such as high residential density, well-connected streets, and mixed land use have been associated with more walking for transport (5-7). Yet, the vast majority of the evidence is derived from studies in high income countries, including the United States, Northern Europe and Australia (5, 6, 8-10). In these settings, the American operationalization of "walkability" (a composite measure for residential density, commercial density, connectivity and land use mix) (5, 11), is consistently associated with more physical activity (5, 6, 8-10). Furthermore, access to physical activity infrastructure (i.e. parks and trails) is positively related to recreational physical activity (6, 12, 13).

Particularly in Latin America, findings from Brazil, Colombia and Mexico suggest differences from what is known for high income countries. Previous reports from Salvo et al using data from the Mexican site of the International Physical Activity and the Environment Network (IPEN) Adult project (www.ipenproject.org) showed that in Mexico objective measures of walkability, as well as residential density, commercial density, and street connectivity, and density of transit stops, were inversely related to accelerometer-based physical activity (14). Similarly, objectively measured park availability was not associated with physical activity when parks were perceived as safe, whereas a negative relationship was observed when parks were perceived as unsafe (14).

This dissertation takes upon results observed by Dr. Salvo between objectively measured features of the built environment and physical activity, and expands the current knowledge by exploring the relationships between perceptions of the built environment and physical activity, as well as objective and perceived measures of the built environment, using the data collected for the study in Cuernavaca, Mexico. The following sections provide a brief review of the theoretical and empirical background that support this dissertation.

I.II. The built environment and physical activity

Ecological models propose that intrapersonal (biological, psychological), interpersonal or cultural, organizational, physical environment (built, natural), and policy (laws, rules, regulations, codes) factors have an influence upon PA behavior as well as being interdependent across levels (4). However, it has been argued that ecological models lack specificity about which characteristics of the environment might influence behavior, forcing researchers to look elsewhere for conceptualizations of the environment and, thus, making comparability and extraction of overall conclusions difficult.[15] In an attempt to differentiate the causal role of environmental influences on behavior, Kremers et al proposed a dual-process view on the environmental influences on energy balance related behaviors, such as physical activity (16). They propose that behavior is the result of a simultaneous influence of conscious and unconscious processes, and that the environment influences physical activity both indirectly and directly (Figure 1). The direct influence reflects the automatic, unconscious, influence of the environment on behavior, (e.g. walking towards transit stop in a city with a reliable public transportation service). The indirect causal mechanism reflects the mediating role of other variables, such as perceptions of the built environment (17, 18), in the influence of the environment on behavior. Various specific factors are postulated to moderate the conscious and non-conscious processes involved in PA behavior. It has been suggested that environmental factors may have differential effects on various demographic sub-groups of the population. Evidence shows the differential impact of the environment on PA with respect to gender (19-22), socioeconomic status (23), and ethnicity (24).

Objective and perceived measures have been used to assess environmental characteristics (11, 25, 26). However, perceived measures may play an important and distinct role in influencing physical activity, and allow for assessing relevant aspects of the built environment that are difficult to measure objectively (e.g. aesthetics and safety) (27, 28). Perceptions result from filtering characteristics through individual standards of evaluation (29, 30); thus, two individuals may perceive the same environment differently (17, 18, 28, 31-41). Individuals' perceptions of environments are collected

by self-report. However, these measures are not simple proxies for objective measures. Individuals' perceptions are distinguished from more objective aspects, and both are likely to be important influences on behavior (4, 18). Studies in high income countries that evaluate the simultaneous association between objective and perceived measures of the BE and physical activity have found that both contribute to the amount of physical activity (28, 31, 42).

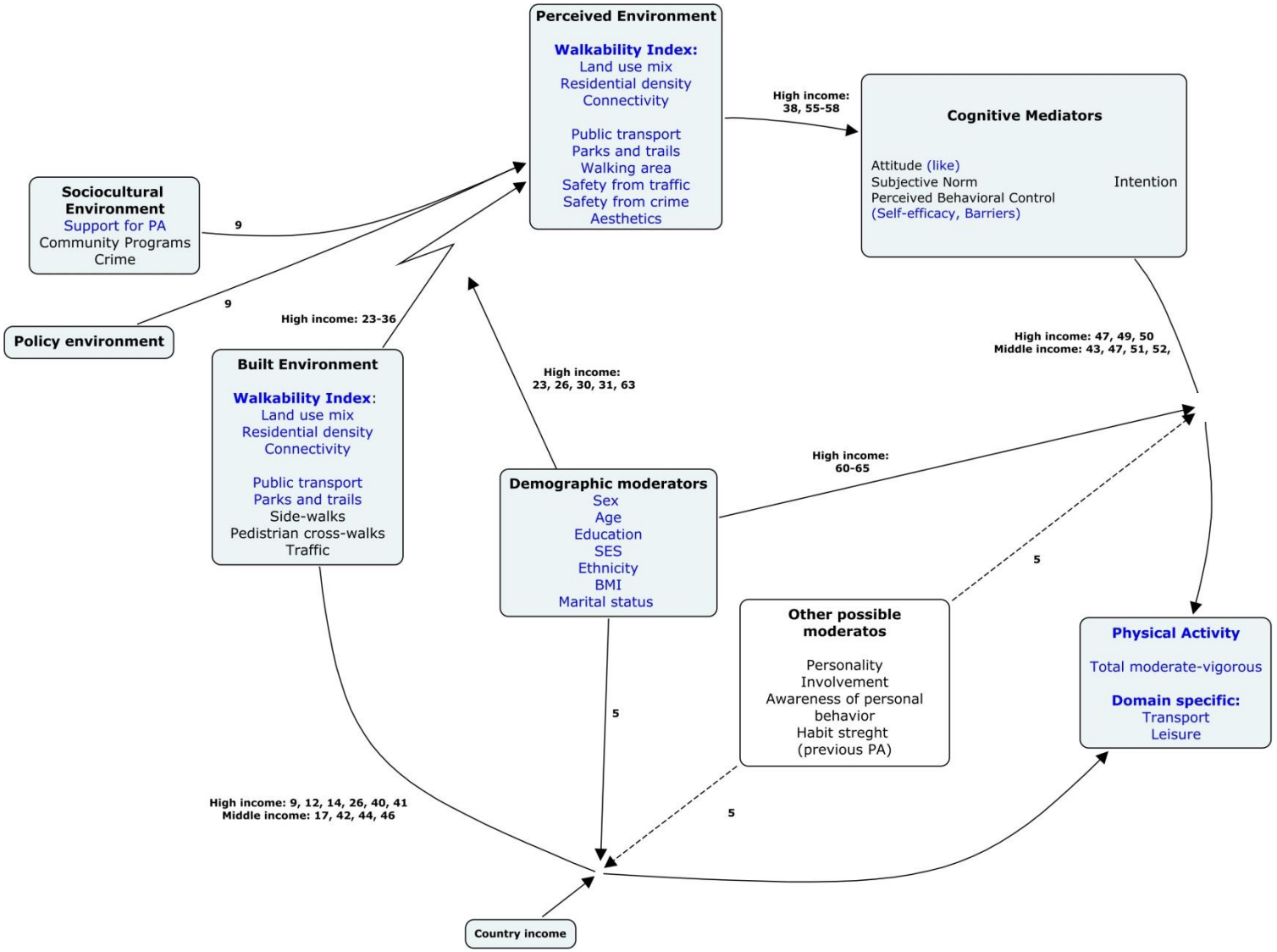

Figure 1. The dual process view on the environmental influences on physical activity behavior, considering perceptions of the built environment as mediator in the influence of the environment on behavior. Adapted from Kremers et al.(16)

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A thorough review of the relationship between perceived environmental features and physical activity was conducted when preparing the research protocol of this dissertation in 2014. Presenting the complete results of this review is out of the scope of this dissertation, however a summary of findings is presented in Table 1. Briefly, in high income countries positive and consistent associations have been found between physical activity and perceived presence of physical activity facilities (43), sidewalks (43), shops and services (43), and aesthetics (44), as well as perceiving traffic not to be a problem (43). Furthermore, the strongest effect of the BE on physical activity is found in people whose perceptions are positively associated with objective measures (17, 18). Sub-groups with low levels of association between perceived and objective measures of the BE include older adults (28), people with low socioeconomic status (17), married or cohabitating adults (28), with children in the household (17), and individuals who are overweight (17) or have low physical activity (35, 36, 45).

In middle income countries, evidence on the relationship between perceived measures of the BE and physical activity is scarce and results are not consistent (46-52). Furthermore, the association between perceived and objective measures of the BE or patterns of associations by sub-groups have not been explored. Associations between objective and perceived measures of the environment depend on the congruence between neighborhood definitions. Studies in high income countries have suggested that 400-m buffer sizes adequately capture the perceived walkable neighborhood area in adults (33, 42, 53). However, no evidence exists on the optimal buffer size in Latin America. Given that IPEN-Mexico collected information on 500-m and 1 km buffers, for this dissertation 500-m buffer sizes were used.

Context-specific evidence on those objective and perceived BE features relevant for PA promotion is needed in order to design, implement and target appropriate environmental strategies to increase physical activity. Information on groups of people in which perceptions of these features do not correspond to objective measures could be used to better target such interventions. For example, interventions aimed at improving relevant perceptions of the BE could be an efficient approach, especially if targeted to population groups with low perceptions but living in objectively high walkable environments.

Particularly in Latin America, while evidence from Brazil and Colombia continues to build up,(46, 49-51) Mexico has been falling behind in physical activity research (52). This is undesirable given the epidemiologic profile of the country, where more than 70% of the adult population is either overweight or obese,(54) and diabetes is the second leading cause of death (55).

Table 1. Summary of the evidence relating perceived environment features and objectively measured and self-reported physical activity across different settings

Perceived Environment feature	Self-reported physical ativity				Objectively measured physical activity			
	Variable	Setting	Association	Reference	Variable	Setting	Association	Ref
Recreation facilities	LPA or Total PA	HIC	+	Duncan, 2005 (43)				
	LPA	BZ	+	Hallal, 2010 (49)				
	Meeting PA rec	HK & LIT	+	Ding, 2011 (13)				
	Walking for leisure*	HIC&MIC	+	Sugiyama, 2014 (56)				
Pedestrian infrastructure and safety	LPA or Total PA	HIC	+	Duncan, 2005 (43)	MVPA*	HIC&MIC	+	Cerin, 2014 (57)
	LPA	BZ	+	Hallal, 2010 (49)				
	Meeting PA rec	COL, HK, JAP, LIT	+	Ding, 2011 (13)				
	Walking for leisure	BZ	-	Gomes, 2011 (46)				
	LPA and Total PA	BZ	+	Parra, 2011 (48)				
	Walking for leisure	HIC&MIC	NS	Sugiyama, 2014 (56)				
Aesthetics	Walking for leisure*	HIC&MIC	+	Sugiyama, 2014 (56)	MVPA	HIC&MIC	+	Cerin, 2014 (57)
Traffic safety	LPA or Total PA	HIC	+	Duncan, 2005 (43)				
	Walking for leisure	BZ	NS	Hallal, 2010 (49)				
	Walking for leisure	HIC&MIC	NS	Sugiyama, 2014 (56)				
No barriers for walking	Walking for leisure	HIC&MIC	NS	Sugiyama, 2014 (56)	MVPA *	HIC&MIC	+	Cerin, 2014 (57)
Feeling safe from crime	Walking for transport	BZ	+	Parra, 2011 (48)	MVPA *	HIC&MIC	+	Cerin 2014
	Walking for leisure	BZ	NS	Gomes, 2011 (46)				
	Meeting PA rec	JAP	+	Ding, 2011 (13)				
		Norway	-					
Land use mix	Biking for transport	LAC	+	Parra, 2011 (48)	MVPA	HIC&MIC	J shape	Cerin 2014 (57)
	LPA or Total PA	HIC	+	Duncan, 2005 (43)				
	Meeting PA rec	BZ, HK, JAP, & NZ	+	Ding, 2011 (13)				
	Walking for leisure*	HIC&MIC	+	Sugiyama, 2014 (56)				
Street connectivity	Walking for leisure*	HIC&MIC	+	Sugiyama, 2014 (56)	MVPA *	HIC&MIC	+	Cerin 2014 (57)
Residential density	Walking for leisure	HIC&MIC	Inverted U	Sugiyama, 2014 (56)	MVPA*	HIC&MIC	Inverted U	Cerin, 2014 (57)
	Meeting PA rec	Norway	+	Ding, 2011 (13)				
		JAP	-					
Few cul-de sacs	Walking for leisure*	HIC&MIC	+	Sugiyama, 2014 (56)	MVPA *	HIC&MIC	+	Cerin 2014 (57)
Transit stop near home	Meeting PA rec	BEL, HK& JAP	+	Ding, 2011 (13)				
		COL**	-					

* Relationships were found only in bivariate analysis, but not in fully adjusted models **Negative relationship, but non-significant. PA= Physical activity, MVPA= Moderate to Vigorous Physical Activity; LPA= Leisure-time physical activity, TPA= transport physical activity, BEL= Belgium, COL= Colombia, JAP= Japan, HK=Hong Kong, BZ= Brazil, NZ= New Zealand, HIC=High income countries, MIC= Middle Income Countries, LAC= Latin American Country

I.III. The built environment in Cuernavaca

Associations between the built environment and physical activity may be driven by contextual, cultural or psychosocial factors specific for each context. The Latin America urban environment differs markedly from that found in those commonly studied high income countries. For example, population density is typically higher (58), public transportation is used more frequently and by a higher proportion of the population (59), human activity generally focuses in central districts (60), road and traffic safety is poorer (61), and crime rates and social inequalities are higher (62). Due to the cultural, social, economic and structural differences between high income countries and Latin America, differences in associations between the built environment and physical activity are expected.

Cuernavaca is in the central region of Mexico and is considered mid-sized (total land mass of 150 km^2), with a population of 365,000 inhabitants according to the 2010 Mexican Census. It has very similar rates of overweight and obesity as the whole country (54), and can be considered a regular Mexican city in size and structure. As other Mexican cities, the city lacks of cycling infrastructure and Cuernavaca's downtown is a small (2 km^2) vivid area that harbors a population of 27,000 people (6,000 residents and 21,000 employees) (63). However, certain features of the built and social environment make it unique.

The topography of the city is one of its many peculiarities. Cuernavaca has many steeps and slopes and is carved up by a system of 46 gorges distributed along the city from north to south. Given these topographic characteristics, the city has better street connectivity from north to south than from east to west. In spite of the former, a study comparing the built environment using geographic information systems (GIS) across 15 cities from culturally and environmentally diverse countries ranked Cuernavaca among the cities with the highest intersection density (64).

Public transportation in Cuernavaca is provided by a total of 20 bus routes. Contrary to bus systems available in other cities where bus stops are generally spaced within walking distance of each other, in Cuernavaca buses stop whenever and wherever a potential rider signals the driver to do so (65). Additionally, given the reduced connectivity from east to west, several routes may circulate through the same streets going from north to south. These characteristics make public transportation highly available in the city, as shown by the high perceived proximity to transit stops by most participants and the fact that among 15 cities around the world, Cuernavaca had the highest availability of objectively derived transit stops (64). A recent study conducted in the city's downtown reported an oversupply of public transportation up to 5 times higher than the estimated demand of transit trips (63).

The crime situation is also worth mentioning. IPEN-Mexico collected data when Mexico was enduring a period of very high crime (2011), and Cuernavaca was one of the most affected cities. According to the National Survey on Victimisation and Security Perception conducted by the Mexican Statistics Bureau (INEGI) in 2012, in the state of Morelos 43.0% of adults reported having stopped going out for a walk out of fear of suffering a crime (66). This number was the fifth highest in the country, after Tamaulipas (55.8%), Nuevo León (52.2%), Coahuila (48.4%) and Chihuahua (47.9%) (66).

I.IV. Objective and self-reported measures of physical activity

Measures of physical activity for health promotion purposes are usually by self-report, through the completion of questionnaires, or using objective measures, such as those obtained from accelerometers (67). Evidence suggests that although physical activity questionnaires, such as the International Physical Activity Questionnaire, are useful for ranking participants into physical activity levels, they are less precise assessing the absolute volume (intensity, frequency and duration) of physical activity (e.g. the total amount of time spent in moderate-to-vigorous physical activity) compared to accelerometers. Despite the former, accelerometers are unlikely to fully replace self-report measures because both measurements capture different dimensions and domains of physical activity, and hence, perceived measures of the built environment may relate differently with self-reported and objectively measured physical activity.

Physical activity questionnaires are able to measure physical activity domains. Evidence suggests that the relations between neighborhood environmental attributes and physical activity are domain-specific (68-70). For example, while sidewalk availability may be important for walking for transport (69, 70), other features, such as availability and accessibility of recreational facilities (e.g., parks) and aesthetics, could be a relevant factor for leisure-time walking (68, 69). This information is valuable for better targeting physical activity interventions toward specific behaviors. Nevertheless, compensatory mechanisms may exist between physical activity domains, and increases in one physical activity domain (e.g. occupational physical activity) may be compensated by decreases in another domain (e.g. leisure-time physical activity) **(71)**.

In contrast, accelerometers measure accelerations in physical motion, and do not directly measure behavior (72). Although accelerometers do not take into account the domain and setting of physical activity (e.g. indoor vs. outdoor; transport vs. leisure), they may provide a superior measure for identifying relevant environmental correlates associated with higher physical activity levels

while minimizing the effect of compensatory mechanisms between types and domains of physical activity.

I.V. IPEN-Mexico preliminary results

This dissertation is part of the IPEN-Mexico project (IPEN: International Physical Activity Environment Network). IPEN is a collaborative network of researchers from twelve countries studying the associations between physical activity and the BE. The IPEN Adult project was designed to examine associations of neighborhood environment with physical activity across 12 environmentally- and culturally-diverse countries using state-of-the art, common measures across countries (for more information visit www.ipenproject.org) (73). IPEN Mexico is a cross-sectional, multistage clustered study in the city of Cuernavaca. Data collection and data set preparation for the Mexican site of the IPEN Adult project were conducted in 2011 and 2012 and analyses are ongoing.

Previous reports from Salvo et al using this dataset showed that Mexican adults were more active during weekdays than weekends, suggesting that physical activity may be more strongly driven by necessity (transport) than by choice (leisure) (74). As for the relationship between objective measures of the built environment and physical activity, it was reported that walkability, as well as residential density, commercial density, and street connectivity, and density of transit stops, were inversely related to accelerometer-based physical activity (14). Similarly, objectively measured park availability was not associated with physical activity when parks were perceived as safe, whereas a negative relationship was observed when parks were perceived as unsafe (14).

There are several possible explanations for the counterintuitive associations between physical activity and objective measures of the built environment in Mexico. Up to now the definition of categories of objectively measured walkability has been sample specific, using quartiles, quintiles or deciles of the distribution of the study sample. Definitions of high and low walkability may not represent the same concept across sites. For example, what is defined as “low walkability” in Mexico, may be “high walkability” in other countries. Most studies have analyzed the walkability index and not the individual components. However, individual components may not be associated with physical activity individually or associations between individual components and physical activity may differ to those observed between the walkability index and physical activity. It is also possible that individual studies have only shown partial relationships between walkability and physical activity. Pooled analysis using IPEN data from 15 cities have shown curvilinear (U, inverted U or J shaped) relationships between physical activity and some perceived measures of the built environment (i.e land use mix

access and residential density) (56, 57). Inaccurate objective measures may also account for these unexpected associations because data sources for Geographic Information Systems in Mexico are not as detailed and up to date as those in high income countries. Issues related with accelerometer-based physical activity may also account for these relations. Physical activity patterns in middle-income countries may differ to those in high income countries. For example, transport physical activity is more frequently used and by a higher proportion of the population (59). Using accelerometer-based physical activity may not adequately capture such differences. Another possible explanation is that associations between the built environment and physical activity are driven by contextual, cultural or psychosocial factors specific for each context.

I.VI. Research questions

In order to inform stakeholders and to design, implement and target appropriate environmental strategies to increase physical activity among Mexicans, local studies that take into consideration context-specific subjects, such as perceptions, are needed. With these dissertation we aimed to fill this gap in literature by exploring the following questions:

1. *Is perceived environment associated with objective and self-reported physical activity in Mexican adults living in the city of Cuernavaca?*
2. *Are objective measures of the BE within a 500 m buffer related with perceptions of the BE from Mexican adults living in the city of Cuernavaca?*
3. *Are associations between objective measures of the BE within a 500 m buffer and perceptions of the BE moderated by demographic characteristics?*

This dissertation presents the results of the three analyses addressing the questions above using data from the Mexican site of the IPEN adult project. Study I aimed to estimate the associations between perceived environment and accelerometer-based physical activity (75), and is currently in press at the American Journal of Preventive Medicine. Study II tested the correspondence between objective and perceived measures of the built environment for physical activity, and assessed whether certain variables modified these relationships (76). This manuscript was published at Preventing Chronic Disease in June 2016. Finally, Study III estimated the associations between perceived environment and self-reported leisure-time walking, moderate-to-vigorous leisure-time physical activity, and transport physical activity (77). This manuscript was submitted for publication to Preventive

Medicine in May 2016. Considering the results of the three analyses, a final discussion, policy implications and directions for future research are provided in the final section of this dissertation.

I.VII. Hypoteheses

Due to the cultural, social, economic and structural differences of Mexico with respect to high income countries where the majority of the evidence linking physical activity to the built environment comes from, the characteristics of the city of Cuernavaca, and based on reported associations in literature on these relationships from middle income countries and Latin-America (Table 1), we hypothesized the following:

1. Objectively measured MVPA will be positively associated with proximity and access to small and large parks, pedestrian infrastructure and safety from crime; negatively associated with proximity to transit stops, and not associated with traffic safety, aesthetics, few cul-de-sacs, no major barriers for walking, as well as the three components of the American definition for walkability (residential density, land use mix and street connectivity).
2. Walking for leisure will be positively associated with land use mix, residential density, feeling safe from crime, feeling safe at parks, and proximity and access to small and large parks, and not associated with street connectivity, few cul-de-sacs, no barriers for walking, traffic safety, aesthetics, and proximity to transit stops.
3. Leisure-time moderate to vigorous physical activity will be positively associated with pedestrian infrastructure, feeling safe from crime, feeling safe at parks, and proximity and access to small and large parks, and not associated to land use mix, residential density, street connectivity, few cul-de-sacs, no barriers for walking, traffic safety and aesthetics.
4. Walking for transport will be positively associated with land use mix, street connectivity and pedestrian infrastructure; negatively associated with proximity to transit stops, and no association will be found with residential density, few cul-de-sacs, no barriers for walking, traffic safety, feeling safe from crime, feeling safe at parks, and proximity and access to small and large parks.
5. Perceived and objective measures of the BE will have a low association. Specifically, residential density, connectivity, and land-use mix will have a non-linear relationship.
6. Perceptions will be least associated with objective measures of the BE among people from the high socioeconomic status, not meeting physical activity recommendations, and women.

Part II. Study I. Perceived Neighborhood Environment and Physical Activity

Jauregui, A., Pratt, M., Lamadrid-Figueroa, H., Hernandez, B., Rivera, J.A., Salvo, D., 2016. Perceived Neighborhood Environment and Physical Activity: The International Physical Activity and Environment Network Adult Study in Mexico. Am J Prev Med. 51:271-79.

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Perceived Neighborhood Environment and Physical Activity

The International Physical Activity and Environment Network Adult Study in Mexico

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Introduction: There is compelling evidence linking physical activity with environmental characteristics in high-income countries, but evidence among low- and middle-income countries is scarce and results are inconsistent. This study assessed associations between perceived measures of the built environment and objectively measured physical activity among Mexican adults.

Methods: A population-based study of adults aged 20-65 years was conducted in Cuernavaca, Mexico, in 2011 (N=629). Participants wore an accelerometer for 7 days. Perceived environment data were obtained by questionnaire. In 2014, multiple regression models estimated the association between perceived environmental variables and total moderate to vigorous physical activity (MVPA); MVPA within 10-minute bouts was analyzed using a two-part model.

Results: Easy access to neighborhood parks and close proximity to metropolitan parks were positively associated with total MVPA. Proximity to metropolitan parks was also positively related to any MVPA within bouts among women. High perceived aesthetics among those of low SES and high perceived safety from crime among men were positively associated with total MVPA and MVPA within bouts. Having few cul-de-sacs within the neighborhood and proximity to transit stops were inversely related to total MVPA.

Conclusions: Access to parks, aesthetics, and safety from crime are important correlates of physical activity among Mexican adults. Yet, this study finds no association for other environmental features usually thought to be important for increasing activity levels. These findings highlight the importance of conducting more studies in low- and middle-income countries that examine the relationship between physical activity and the built environment.

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Introduction

Physical inactivity causes the same number of deaths each year as tobacco use and is a risk factor for Type 2 diabetes and heart disease,[1,2] the leading causes of death among Mexicans.[3] Trends in Mexico suggest that physical inactivity is increasing.[4] Identifying the correlates of physical activity is crucial for developing local strategies to promote physical activity with population-wide effects.

Individual, interpersonal, and environmental factors influence physical activity.[5] Population-level increases in physical activity may be achieved more effectively through strategies that target the built environment.[6]

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There is compelling evidence linking physical activity with built environment characteristics such as residential density, commercial density, street connectivity, land use mix,[7–9] recreational facilities,[9–12] pedestrian infrastructure,[9] aesthetics,[13] and traffic safety.[9] Yet, the vast majority of the evidence is derived from studies in high-income countries.[7,11,14–16]

Research in this field in Latin American countries is scarce, and results are not consistent with those from high-income countries.[17,18] Previous reports from this research team showed that in Mexico, objectively measured residential density, commercial density, and street connectivity were inversely related to physical activity.[17]

Objective and perceived measures have been used to assess environmental characteristics.[8,17,18] Perceived measures may play an important and distinct role in influencing physical activity, and allow for assessing relevant aspects of the built environment that are difficult to measure objectively (e.g., aesthetics and safety).[19,20] In order to improve the understanding of the environmental correlates of physical activity in a Latin American setting, this study aimed to estimate the associations between perceived environment and objectively measured physical activity among adults in Mexico.

Methods

Study Design and Setting

This study was part of the International Physical Activity and Environment Network (IPEN)– Mexico project.[21] IPEN–Mexico is a cross-sectional, population-based study of adults in Cuernavaca, Mexico (365,000 inhabitants). Cuernavaca is in the central region of Mexico. It has many steep slopes and has presented an increase in crime in the past years.[22] Data collection and data set preparation were conducted in 2011–2012. This analysis was conducted in 2014.

Participants

A representative sample of adults was selected using Census tracts as primary sampling units. Census tracts were stratified in four levels of SES and two levels of objectively measured walkability.[7] Eight Census tracts per stratum were randomly selected, yielding 32 (out of 123) study Census tracts. Seven blocks were randomly selected per Census tract and two to four households were selected per block.[23] Data were collected in person via two home visits. Eligible participants were aged 20–65 years, able to walk, and permanent residents of that household. Participants signed informed consent forms before data collection. The study was approved by the IRB of Emory University and the Instituto Nacional de Salud Pública of Mexico.

Measures

Physical activity was collected with GT3X Actigraph accelerometers using 60-second epochs. Participants were given the device during the first home visit and wore it on their right hip for 7 days. A valid measurement had at least 5 days with 10 hours per day. Total minutes per week of moderate to vigorous physical activity (MVPA) and minutes per week of MVPA occurring within bouts of $\geq$10 minutes were calculated. Total MVPA was scored with MeterPlus 4.2 using Freedson's cut points for adults.[24] Bouts were defined as having a duration of $\geq$10 minutes, consisting of $\geq$80% of MVPA, and not having breaks lasting $>$2 minutes.[17] Bouts of MVPA were calculated using MatLab, version 7.7.

Trained field workers administered the Abbreviated Neighborhood Environment Walkability Scale (ANEWS) adapted for use in Latin America during a second home visit.[25] ANEWS consists of 58 items divided into ten subscales[26]: residential density, land use mix diversity, land use mix access, street connectivity, few cul-de-sacs, no major physical barriers for walking, pedestrian infrastructure, aesthetics, traffic safety, and safety from crime. High test–retest reliability (intraclass correlation coefficient $>$0.75) has been reported for most of these subscales.[27–29] This version included characteristics of the built environment present in Latin American urban settings such as hilliness, proximity to public transportation, park safety, and easy access and proximity to small and large parks.[25] Variables were calculated as per the ANEWS protocol (Appendix Table 1, available online).[26]

Self-reported age, sex, education level, marital status, individual-level SES (based on 25 questions on household characteristics and assets, as used by the National Health and Nutrition Surveys of Mexico[30]), and motor vehicle ownership were collected during the second home visit.

Statistical Analysis

Descriptive statistics (means, frequencies, and 95% CIs) were calculated for all variables. Weekly minutes of total MVPA were log-transformed to improve the normality of the distribution for the dependent variable. No zero values were found in total MVPA, whereas almost 30% of participants did not accumulate any MVPA within bouts.

Linear regression models were used to determine the relationship between perceived environment variables and total MVPA (log-transformed). The selection of relevant environment variables was based on theoretic and empirical criteria. First, environmental variables were introduced one at a time in single environment (independent) variable models, adjusting for sex, age, marital status, SES, motor vehicle ownership, educational attainment, and accelerometer wear time. Next, a full environmental variable model was run, including the same covariates listed above and environmental variables associated with a $p<0.05$ in the single environment variable models, or those considered as theoretically relevant, as discussed below. Regardless of statistical significance, safety from crime, access to parks, pedestrian infrastructure, land use mix, traffic safety, and proximity to transit stops were kept in the full environmental variable model based on reported associations from other middle-income countries.[17,18,22,31,32] The authors tested for all possible interactions between environmental variables and gender as well as SES, but only significant ($p<0.05$) interactions were included in the full environmental variable model. In these cases, subgroup-sliced associations are reported instead of overall main effects.

Preliminary analysis indicated that MVPA within bouts had a distribution with a large number of zeroes and a continuous right-

Table 1. Sample Characteristics: Sociodemographic, Accelerometer-Based Physical Activity[a] (*n*=659)

Characteristic	*n*	% (95% CI)[a]
Gender (%)		
Female	358	50.9 (43.8, 57.8)
Male	301	49.1 (42.2, 56.2)
SES (%)		
Low	194	30.9 (23.6, 39.3)
Medium	159	23.7 (20.2, 27.4)
Medium-high	196	29.4 (24.8, 34.5)
High	110	16.1 (12.9, 19.8)
Education (%)		
Elementary school or less	100	15.0 (12.1, 18.4)
Some or complete middle school	161	25.3 (21.6, 29.5)
Some or complete high school	184	27.1 (23.7, 30.9)
Some or complete college	173	27.1 (23.5, 31.1)
Postgraduate	41	5.4 (3.5, 8.3)
Motor vehicle ownership (%)		
Car	354	53.4 (46.8, 60.0)
Motorcycle	30	4.8 (3.3, 7.0)
Either	362	54.8 (48.0, 61.5)
Marital status (%)		
Single	164	25.4 (22.2, 28.9)
Married or living with someone	422	64.6 (60.2, 68.7)
Separated or divorced	56	7.6 (5.7, 9.9)
Widower	17	2.5 (1.4, 4.4)
Meeting physical activity guidelines (%)		
Total moderate to vigorous physical activity	377	59.0 (54.1, 63.8)
Moderate to vigorous physical activity occurring within bouts of at least 10 minutes	92	13.9 (11.1, 17.3)

[a]Weighted for survey design.

skewed non-zero part. Previous approaches have estimated separate regression models to identify perceived environmental variables associated with (1) likelihood of any physical activity versus no physical activity; and (2) the duration (minutes per week) of physical activity among the subgroup engaging in this behavior.[33] However, a more adequate approach to explore such relationships is to use a two-part model. This model is useful for estimating relationships between variables for mixed discrete–continuous outcomes, while allowing separate mechanisms to determine the likelihood and duration for MVPA within bouts.[34] A logit model was fit for the possibility of observing any MVPA within bouts; then, conditional on a positive outcome, a linear regression model was used to estimate the duration of MVPA within bouts (log-transformed). The same criteria as those used in total MVPA were applied to select relevant perceived environmental variables.

Final models were tested for specification error and multicollinearity. The normality and homoscedasticity assumptions were assessed by graphical methods. The antilogarithms of the regression coefficient estimates (exp[B]) of all models were calculated and reported. All analyses accounted for the complex multistage clustered design and were weighted for probability of selection. Analyses were conducted using Stata, version 13.0, survey procedures (e.g., *svy*).

Results

Of the 677 participants originally recruited, ten had incomplete perceived environmental data and eight did not have enough wear time accelerometry data, leaving 659 participants for analysis. No significant differences in demographic characteristics were found between the analytic and full samples. Participants were aged 42 (95% CI=40.7, 43.2) years on average, 50.9% female, and 54.8% owned a motorized vehicle (Table 1). On average, participants engaged in 222.4 (95% CI=201.2, 243.6) minutes/week of total MVPA and in 66.2 (95% CI=56.4, 75.99) minutes/week of MVPA within bouts. A total of 70.6% respondents reported low (score <50) residential density; 93.0% high land use mix diversity; and 99.6% a transit stop within $\leq$10 minutes' walking distance (Appendix Table 2, available online).

Single environmental variable models identified few cul-de-sacs as negative correlate of total MVPA and proximity to large parks, easy access to small parks, and better access to mixed use as positive correlates ($p<0.05$) of total MVPA after adjusting for covariates (Table 2). These variables, plus the other theoretically relevant environmental variables, were introduced in the full environmental variable model. Only few cul-de-sacs (inverse); proximity to large parks; and easy access to small parks remained significantly associated with total MVPA ($p<0.05$) in the fully adjusted model. Each unit increase in proximity to large parks and easy access to small parks was associated with a 12% (95% CI=6%, 18%) and 16% (95% CI=1%, 35%) increase in total MVPA, respectively. Each unit increase

Table 2. Associations Between Perceived Environment and Total Moderate to Vigorous Physical Activity (Minutes/Week) in Mexican Adults

Variable	Single environmental variable models[a], exp(B) (95% CI)	Full environmental variable model[b], exp(B) (95% CI)
Safety from crime	1.03 (0.94, 1.13)	
Females		0.92 (0.76, 1.11)
Males		**1.14 (1.03, 1.26)**
Easy access to small parks	**1.18 (1.03, 1.34)**	**1.16 (1.01, 1.35)**
Pedestrian infrastructure	1.12 (0.89, 1.4)	0.97 (0.78, 1.21)
Land use mix diversity	**1.18 (1.01, 1.38)**	1.00 (0.86, 1.17)
Land use mix Access	0.95 (0.76, 1.18)	0.86 (0.70, 1.06)
Safety from traffic	1.14 (0.97, 1.33)	1.12 (0.96, 1.31)
Few cul-de-sacs	**0.91 (0.84, 0.99)**	**0.91 (0.83, 0.99)**
Proximity to transit stops	1.07 (0.93, 1.23)	1.08 (0.94, 1.23)
Proximity to large parks	**1.13 (1.07, 1.19)**	**1.12 (1.06, 1.18)**
Aesthetics	1.09 (0.90, 1.31)	
Low SES		**1.47 (1.01, 2.15)**
Medium SES		1.23 (0.95, 1.61)
Medium-high SES		0.90 (0.72, 1.13)
High SES		0.83 (0.64, 1.00)

Note: Exp(B) is to be interpreted as the proportional increase in total minutes per week of moderate to vigorous physical activity associated with a 1-unit increase in the independent variable.
Boldface indicates statistical significance ($p<0.05$).
[a]Regression coefficients are adjusted for sex, age, marital status, individual SES, motor vehicle ownership, educational attainment, accelerometer wear time, and the survey design.
[b]Regression coefficients are adjusted for the same covariates as single environmental variable models, all perceived environment variables listed in the table, and the significant ($p<0.05$) interaction terms "Gender X safety from crime" and "SES quartile X aesthetics." The sliced associations by gender and SES quartile, correspondingly, are presented (Figure 1A and B).

Single environmental variable models did not identify any significant ($p<0.05$) correlate of the probability of weekly minutes of MVPA within bouts (data not shown). The full environmental variable model included only theoretically relevant environmental variables (Table 3). No environmental correlates were associated with any MVPA within bouts in the full sample; however, proximity to metropolitan parks was positively associated with 69% (95% CI=13%, 153%) higher probability of any MVPA within bouts among women, whereas no significant relationship was observed for men (exp [B]=0.94, 95% CI=0.75, 1.18) (Figure 1C). Conditional on engaging in MVPA within bouts, time spent in this outcome was associated with proximity to large parks (positive) and transit stops (inverse): Each unit increase in proximity to large parks was associated with a 12% (95% CI=1%, 24%) increase in MVPA within bouts. Each unit of proximity to transit stops was negatively associated with a 19% (95% CI=10%, 28%) decrease in this outcome. Additionally, the same interactions between aesthetics and SES, as well as between gender and safety from crime, were observed ($p<0.05$) (Table 3). No other significant interactions between environmental variables and gender or SES were observed.

in few cul-de-sacs was associated with a decrease of 9% (95% CI=1%, 17%) in total MVPA (Table 2). The relationship between total MVPA and aesthetics differed by SES ($p<0.05$): Aesthetics were positively related with a 47% (95% CI=1%, 115%) increase in total MVPA among participants of low SES, whereas this relationship decreased in the upper three quartiles of SES (Figure 1A). The relationship between total MVPA and perceived safety from crime differed by gender: High safety from crime was positively related with total MVPA only among men, with a 14% (95% CI=3%, 26%) increase in total MVPA per unit increase in this variable (Figure 1B). No other statistically significant interactions between environmental and sociodemographic variables were observed.

Discussion

This study identified easy access to neighborhood parks, close proximity to large parks, high perceived aesthetics among low-SES participants, and high safety from crime among men as positive correlates for physical activity among adults in Cuernavaca, Mexico. Few cul-de-sacs and proximity to transit stops were inverse correlates of physical activity in this setting.

In line with previous work,[12,33,35,36] close proximity and easy access to parks were positively associated with physical activity. Although Cuernavaca has average green spaces compared to other Mexican cities,[37] the city ranked the lowest among 15 cities worldwide.[38]

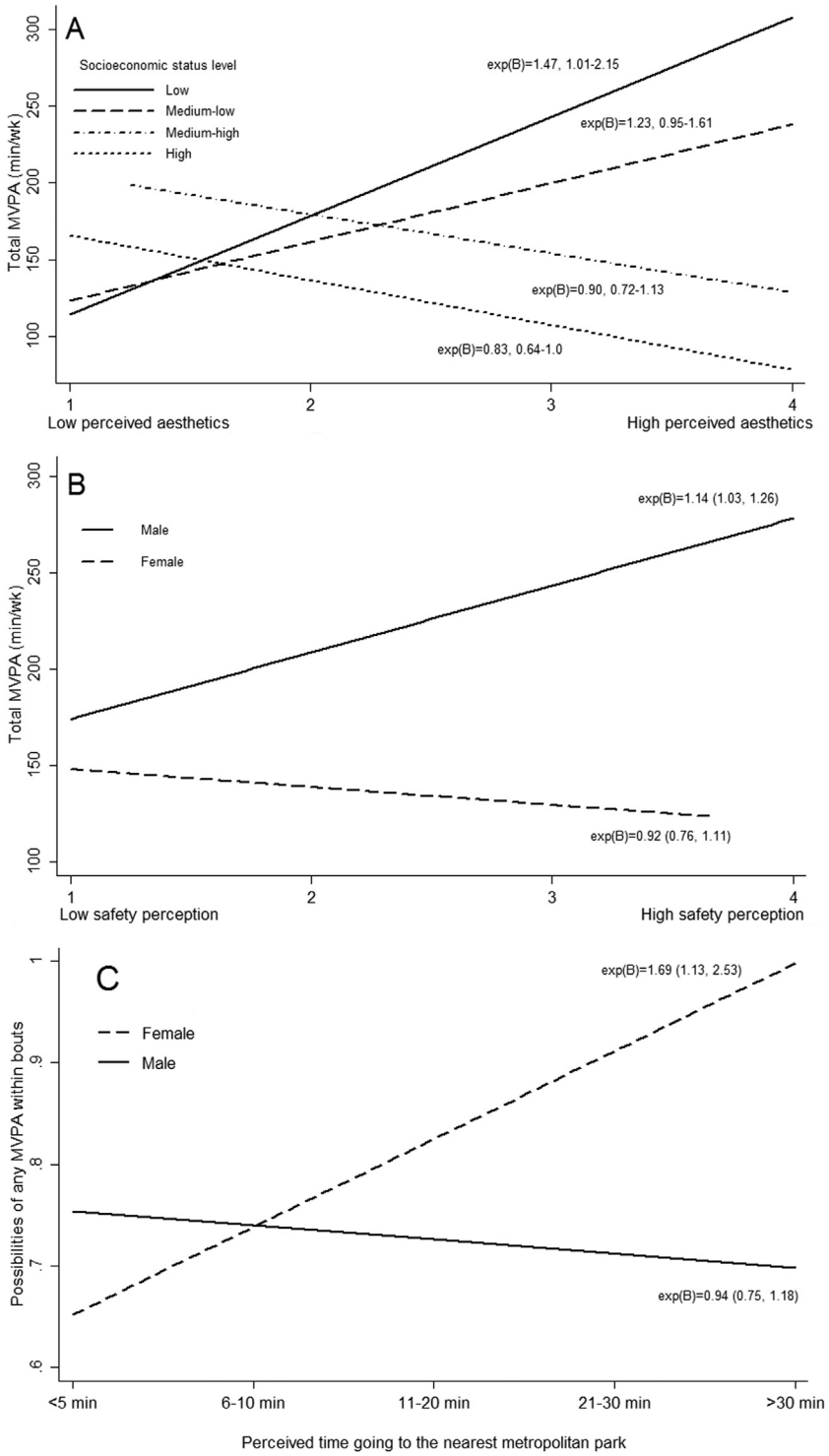

Figure 1. Group associations between physical activity outcomes and perceived environment.

Note: The relationship between perceived aestethics and total MVPA (minutes/week) differed by SES level (A), whereas gender differences were observed in the relationships between total MVPA (minutes/week) and safety from crime (B), as well as any MVPA within bouts and perceived proximity to large parks (C). Estimations adjusted for sex, age, marital status, individual SES, motor vehicle ownership, educational attainment, accelerometer wear time, land use mix diversity, land use mix access, pedestrian infrastructure, traffic safety, few cul-de-sacs, proximity to metropolitan parks, easy access to neighborhood parks, proximity to transit, as well as the survey design. Figure (A) and (B) additionally adjusted for the interactions SES X aesthetics, as well as gender X safety from crime. Figure (C) adjusted for the interaction gender X proximity to metropolitan parks. Cuernavaca, Morelos, 2011. N=659.

MVPA, moderate to vigorous physical activity.

Table 3. Associations Between Perceived Environment and Moderate to Vigorous Physical Activity Within Bouts in Mexican Adults

Variable	Any MVPA within bouts[a], exp(B) (95% CI)	Minutes per week in MVPA within bouts[b], exp(B) (95% CI)
Safety from crime	1.12 (0.85, 1.46)	
Females		0.90 (0.74, 1.10)
Males		**1.29 (1.07, 1.57)**
Easy access to parks	1.49 (0.93, 2.36)	1.02 (0.76, 1.36)
Pedestrian infrastructure	0.95 (0.59, 1.53)	0.97 (0.76, 1.24)
Land use mix diversity	0.95 (0.73, 1.23)	0.91 (0.71, 1.16)
Land use mix access	0.76 (0.42, 1.38)	0.95 (0.73, 1.23)
Traffic safety	1.38 (0.84, 2.28)	1.06 (0.91, 1.25)
Proximity to transit stops	1.04 (0.73, 1.47)	**0.81 (0.72, 0.90)**
Proximity to large parks		**1.12 (1.01, 1.24)**
Females	**1.69 (1.13, 2.53)**	
Males	0.94 (0.75, 1.18)	
Aesthetics	0.99 (0.63, 1.56)	
Low SES		1.16 (0.84, 1.60)
Medium SES		1.37 (0.92, 2.05)
Medium-high SES		0.74 (0.53, 1.05)
High SES		0.81 (0.44, 1.47)

Note: Regression coefficients were estimated using a two-part model. Both equations are adjusted for sex, age, marital status, individual SES, motor vehicle ownership, educational attainment, accelerometer wear time, all perceived environment variables listed in the table, and the survey design.
Exp(B) is to be interpreted as the proportional increase in total minutes per week of MVPA associated with a 1-unit increase on the independent variable.
Boldface indicates statistical significance ($p<0.05$).
[a]Equation additionally adjusted for the significant ($p<0.05$) interaction term "Gender X proximity to large parks." The sliced associations by gender are presented (Figure 1C).
[b]Equation additionally adjusted for the significant ($p<0.05$) interaction terms "Gender X safety from crime" and "SES quartile X aesthetics." The sliced associations by gender and SES quartile, correspondingly, are presented.
MVPA, moderate to vigorous physical activity.

Modifying the built environment in order to increase access to large parks may be challenging in old cities such as Cuernavaca. Given that objective measures are not always consistent with perceived measures, in some circumstances increasing awareness, rather than modifying the physical environment, may be a more effective strategy for increasing MVPA, especially if targeted to population groups with low perception scores but living in objectively derived activity-friendly environments.[39] It has been suggested that individuals who are less physically active, older, and living with children have a poorer awareness of their neighborhood.[40,41] In addition, recovering public spaces and providing access for leisure physical activity, such as the *ciclovías* or free physical activity classes in public spaces, may be considered.[42,43] These strategies have shown promise for increasing physical activity at a population level in Latin America.[44]

Gender differences have been observed in the relationship between environmental features and physical activity.[45,46] In this study, proximity to large parks was positively related with higher probabilities of any MVPA within bouts among women. This finding is important, as women in Mexico have higher rates of physical inactivity than men.[4] Given the potential relevance of this finding for female physical activity promotion strategies, future research should explore the reasons behind this relationship. Likewise, safety from crime was positively related to physical activity only among men. Perhaps this environmental feature is more relevant for men in Cuernavaca given the high crime rates in the city and because injuries and interpersonal violence are leading causes of healthy life lost among Mexican men.[22,47] It is also possible that men are physically active in places where security perceptions are more relevant (e.g., streets). According to these data, safety from crime was mildly correlated with perceived traffic safety, aesthetics, pedestrian infrastructure, and no major barriers for walking ($r=0.11–0.27$, $p<0.05$ for all, data not shown). Future analyses should explore gender-specific relationships among place, security perceptions, and physical activity.

Aesthetics were positively associated with physical activity only in the low-SES group. Previous reports on the relationship between aesthetics and physical activity from other Latin American countries are inconsistent.[18] Perceived aesthetics are hypothesized to encourage engagement in leisure-time activities through the provision of clean and well-maintained infrastructure and attractive buildings and natural elements.[11] Given that

low-SES individuals accumulate more necessity-driven physical activity, this relationship was unexpected. Perhaps, transport-related activities in low-SES individuals make them more aware of their neighborhood and therefore more susceptible to environmental influences on physical activity. Awareness may account for this and other unexpected associations from studies conducted in other settings. Future analyses exploring the relationship between objective and perceived measures of the built environment may provide a better understanding of this association.

In contrast to previous reports from high-income countries,[33] few cul-de-sacs and proximity to transit stops were inversely related with physical activity. Results are consistent with previous findings from this data set reporting a negative relationship between total MVPA and objectively measured connectivity and transit density.[17] Cul-de-sac density is an inverse measure of street connectivity. Among 15 international cities, Cuernavaca had the highest and second highest transit and intersection density, respectively.[38] As a result of high intersection density, cul-de-sac density is low in Mexico. Perhaps in an environment with high street connectivity and low availability of public recreation spaces,[38] cul-de-sacs provide a safe space to engage in leisure activities. Future studies exploring the role of cul-de-sacs in physical activity engagement could confirm this hypothesis. Additionally, in Cuernavaca, buses stop whenever and wherever a potential rider signals the driver to do so (97% report living within high proximity of a public transit stop). Studies in Bogota, Colombia, where a similar transit system exists (referred to as "feeder buses") have reported inverse relationships between walking for transport and feeder buses.[48] A potential strategy for physical activity promotion in Cuernavaca could be to designate and enforce the use of formal bus stops with enough distance between each other.

Walkability is a composite measure of residential density, street connectivity, and land-use mix.[7,8] Considering the lack of association between perceived residential density and land use mix with physical activity, the inverse relationship between a perceived measure of connectivity (few cul-de-sacs), and previous findings from this sample reporting negative relationships between objectively measured walkability,[17] walkability may not be the best measure to rate the activity-friendliness of urban Mexican settings. In fact, results highlight unique environmental characteristics of the Mexican urban context, such as the ubiquitous perceived access to transit stops and high land use mix perception. These characteristics may account for the identified context-specific relationships.

Limitations

This is the first study to examine perceived environmental correlates of physical activity in the Mexican urban context and builds upon evidence in other Latin American countries. Limitations include the cross-sectional design, which does not allow determination of causality. Given the high crime situation during data collection, findings on perceived safety from crime may be valid for the crime rate perceived by the population at the time of data collection and may change as crime rate perception changes. Self-report measures of environmental attributes may not represent accurate objective measures[20]; however, they are still relevant because objective and perceived environmental attributes may be independently associated with physical activity.[20] Additionally, for some attributes, such as aesthetics and perceived safety from crime, environmental perceptions may be considered as criterion measures.[19] Accelerometers do not take into account the domain and setting of physical activity (e.g., indoor versus outdoor, transport versus leisure), which could help to better elucidate these relations. Nevertheless, compensatory mechanisms may exist between physical activity domains. For example, an occupational intervention to increase physical activity reported that increases in activity during working hours were compensated for by reducing activity outside these hours.[49] Overall, objectively derived physical activity may be less sensitive to compensation mechanisms and therefore be superior as a single measure for identifying relevant environmental correlates associated with higher physical activity levels while minimizing the effect of compensatory mechanisms between types and domains of physical activity. MVPA within bouts is a variable with many zero values. Advanced analytic methods were employed to examine the strength of associations between perceived environmental features and MVPA within bouts. This new approach showed similar results to those previously used in the field. The principal strengths of this study are its representativeness of the population of Cuernavaca, supported by the random sampling design, the use of objective measures of physical activity, and the use of cross-validated, comparable measures of perceived environmental attributes.[26]

Conclusions

This study identified environmental perceptions that may be relevant for physical activity promotion among Mexican adults. Perceived access to parks, aesthetics, and safety from crime were important correlates of physical activity. Other environmental features usually thought to be important for increasing activity levels among adults,

such as residential density and land use mix, were not related to physical activity among Mexican adults, stressing the importance of conducting more studies in low- and middle-income countries examining these relationships.

AJ performed the statistical analysis, interpreted the data, and drafted the manuscript. MP made substantial contributions in selecting the appropriate statistical analyses, interpreting the data, and revising the manuscript critically for intellectual content. HL helped analyze the data and provided statistical expertise and advice. BH and JR made substantial contributions in selecting the appropriate statistical analyses, interpreting data, and revising the manuscript critically for intellectual content. DS helped draft the manuscript, contributed in selecting the appropriate statistical analyses, interpreting data, and critically revising the manuscript. DS and MP conceived, designed, and executed the study. All authors read and approved the final manuscript.

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Appendix

Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.1016/j.amepre.2016.03.026.

Appendix Table 1. Definition and operationalization of perceived environmental features using the Latin American version of the ANEWS.

ANEWS sub-scale	ANEWS items	Data operationalization
Residential density	1) How common are detached single-family residences in your neighborhood 2) How common are townhouses or row houses of 1-3 stories in your neighborhood 3) How common are apartments or condos 1-3 stories in your neighborhood 4) How common are apartments or condos 4-6 stories in your neighborhood 5) How common are apartments or condos 7-12 stories in your immediate neighborhood 6) How common are apartments or condos more than 13 stories in your immediate neighborhood Five response options were provided, from "none", coded as zero, to "all", coded as 4.	The score was computed using the following formula:[a] Single-family detached + (12 * row houses/townhouses 1-3 stories) + (10 * apts/condos 1-3 stories) + (25 * apts/condos 4-6 stories) + (50 * apts/condos 7-12 stories) + (75 * apts/condos 13+ stories).
Land use mix diversity	About how long would it take to get from your home to the nearest businesses or facilities listed below if you walked to them?: 1) Convenience/small grocery store, 2) Supermarket, 3) Hardware store, 4) Fruit/vegetable market, 5) Laundry/dry cleaners, 6) Clothing store, 7) Post office, 8) Library, 9) Elementary school, 10) Other schools, 11) Book store, 12) Fast food restaurant, 13) Coffee place, 14) Bank/credit union, 15) Non-fast food restaurant, 16) Video store, 17) Pharmacy/drug store, 18)Salon/barber shop, 19) Your job or school, 20) Bus or trolley stop, 21) Park, 22) Plaza, 23) Gym or fitness facility. Response options for these items were scored using a Likert scale as follows: 1 (1-5 min), 2 (6-10 min), 3 (11-20 min), 4 (21-30 min), and 5 (31+ min).	The score was computed by averaging the scores reported on the 23 destinations.
Land use mix access	1) Stores are within easy walking distance of my home 2) There are many places to go within easy walking distance of my home,	The score was computed by averaging the scores reported on the three items.

	3) It is easy to walk to a transit stop (bus, train) from my home, Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	
Street connectivity	1) The distance between intersections in my neighborhood is usually short 2) There are many alternative routes for getting from place to place in my neighborhood. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	Response options were recoded so that higher values indicated higher levels of intersection density. The score was computed by averaging the scores reported on the two items.
Few cul-de-sacs	1) The streets in my neighborhood <u>do not</u> have many dead-end streets. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was derived from reported scores on the single item.
No major barriers for walking	1) There are many obstacles (canyons/hillsides, big avenues, cul-de sacs, rivers, etc) in my neighborhood that limit the number of routes for getting from place to place. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was derived from reported scores on the single item.
Pedestrian infrastructure	1) There are sidewalks on most of the streets in my neighborhood 2) Sidewalks are separated from the road/traffic in my neighborhood by parked cars 3) There is a grass/dirt strip that separates the streets from the sidewalks in my neighborhood 4) My neighborhood streets are well lit at night. 5) There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood 6) Walkers and bikers on the streets in my neighborhood can be easily seen by people in their homes. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was computed by averaging the scores reported on the six items.

Aesthetics	1) There are trees along the streets in my neighborhood 2) There are many interesting things to look at while walking in my neighborhood 3) There are many beautiful natural sights in my neighborhood 4) There are attractive buildings/homes in my neighborhood Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was computed by averaging the scores reported on the four items.
Traffic safety	1) There is so much traffic along the streets near home that it is difficult or unpleasant to walk in my neighborhood 2) The speed of traffic on most nearby streets is usually slow (50 km/h or less), 3) Most drivers exceed the posted limits while driving in my neighborhood. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	Response options for items 1 and 3 were recoded so that higher values indicated higher levels of traffic safety. The score was computed by averaging the scores reported on the three items.
Safety from crime	1) There is a high crime rate in my neighborhood. 2) The crime rate in my neighborhood makes it unsafe to go on walks <u>during the day</u> 3) The crime rate in my neighborhood makes it unsafe to go on walks <u>at night</u>. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	Response options were recoded so that higher values indicated higher levels of safety from crime. The score was computed by averaging the scores reported on the three items.
Hilliness	1) There are many slopes and inclines in my neighborhood streets that it is difficult to walk	The score was derived from reported scores on the single item.
Access to large and small parks	Can you easily walk to the following parks? a) Large parks b) Small parks Response options were yes or no	The access to large and small parks scores were computed separately from items a) and b), respectively.
Proximity to large parks	1) About how long would it take to get from your home to the <u>nearest large park?</u> Response options for these items were scored using a Likert scale as follows: 1 (1-5 min), 2	The score was derived from reported scores on the single item.

	(6-10 min), 3 (11-20 min), 4 (21-30 min), and 5 (31+ min).	
Proximity to small parks	1) About how long would it take to get from your home to the <u>nearest small park?</u> Response options for these items were scored using a Likert scale as follows: 1 (1-5 min), 2 (6-10 min), 3 (11-20 min), 4 (21-30 min), and 5 (31+ min).	The score was derived from reported scores on the single item.
Park safety from crime	1) The parks, plazas, green and recreational spaces in my neighborhood are unsafe to go during the day. 2) The parks, plazas, green and recreational spaces in my neighborhood are unsafe to go at night. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	Response options were recoded so that higher values indicated higher levels of park safety from crime. The score was computed by averaging the scores reported on the two items.

ANEWS: Abbreviated Neighborhood Environment Walkability Scale

[a] Source: Cerin et al, 2013.(78)

Appendix Table 2. Perceived environmental features among Mexican adults.

Variable	**n**	**%[a]**	**95%CI[a]**
Residential density[b]			
Low (score<50)	449	70.6	(60.7, 78.9)
Medium (50-100)	134	20.2	(14.7, 27.2)
High (score≥100)	76	9.2	(5.6, 14.8)
Land use mix diversity[c]			
Low (score<3)	229	36.8	(27.9, 46.6)
High (score≥3)	430	63.2	(53.4, 72.0)
Proximity to neighborhood parks[c]			
Low (score<3)	251	39.9	(30.2, 50.6)
High (score≥3)	408	60.1	(49.4, 69.8)
Proximity to metropolitan parks[c]			
Low (score<3)	538	81.9	(70.1, 89.8)
High (score≥3)	121	18.1	(10.2, 29,9)
Proximity to the nearest transit stop[c]			
Low (score<3)	5	0.4	(0.1, 1.2)
High (score≥3)	654	99.6	(98.8, 99.9)
Landuse mix access[d]			
Low or medium (score<3)	45	7.0	(4.8, 10.2)
High (score≥3)	614	93.0	(89.9, 95.2)
Easy access to neighborhood parks			
No	176	28.8	(20.8, 38.4)
Yes	483	71.2	(61.6, 79.2)
Easy access to metropolitan parks			
No	377	56.7	(45.8, 67.0)
Yes	282	43.3	(33.0, 54.2)
Street connectivity[d]			
Low or medium (score<3)	200	31.6	26.3, 37.4
High (score≥3)	459	68.4	62.6, 73.7
Infrastructure and safety for walking[d]			
Low or medium (score<3)	530	79.4	(76.0, 82.4)
High (score≥3)	129	20.6	(17.6, 24.0)

Aesthetics[d]			
Low or medium (score<3)	482	75.2	(70.6, 79.4)
High (score≥3)	177	24.8	(20.6, 29.4)
Traffic safety[d]			
Low or medium (score<3)	545	82.1	(76.5, 86.6)
High (score≥3)	114	18.0	(13.4, 23.5)
Neighborhood safety from crime[d]			
Low or medium (score<3)	524	78.7	(74.6, 82.3)
High (score≥3)	135	21.2	(17.7, 25.4)
Park safety from crime[d]			
Low or medium (score<3)	466	68.0	(62.2, 73.2)
High (score≥3)	193	32.0	(26.8, 37.8)
Few cul-de-sacs[d]			
Low or medium (score<3)	262	40.6	(35.6, 45.7)
High (score≥3)	397	59.4	(54.3, 64.4)
No major barriers to walking[d]			
Low or medium (score<3)	162	24.4	(19.3, 30.4)
High (score≥3)	497	75.6	(69.6, 80.7)

[a] Weighted for the survey design
[b] Theoretical range 1-1000
[c] Theoretical range 1-5
[d] Theoretical range 1-4

Part III. Study II. Perceived and Objective Measures of Neighborhood Environment for Physical Activity Among Mexican Adults, 2011

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ORIGINAL RESEARCH

Perceived and Objective Measures of Neighborhood Environment for Physical Activity Among Mexican Adults, 2011

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PEER REVIEWED

Abstract

Introduction
Environmental supports for physical activity may help residents to be physically active. However, such supports might not help if residents' perceptions of the built environment do not correspond with objective measures. We assessed the associations between objective and perceived measures of the built environment among adults in Cuernavaca, Mexico, and examined whether certain variables modified this relationship.

Methods
We conducted a population-based (n = 645) study in 2011 that used objective (based on geographic information systems) and perceived (by questionnaire) measures of the following features of the built environment: residential density, mixed-land use, intersection density, and proximity to parks and transit stops. We used linear regression to assess the adjusted associations between these measures and to identify variables modifying these relationships.

Results
Adjusted associations were significant for all features ($P < .05$) except intersection density and proximity to transit stops. Significantly stronger associations between perceived and objective measures were observed among participants with low socioeconomic status, participants who did not own a motor vehicle or did not meet physical activity recommendations, and participants perceiving parks as safe.

Conclusion
Perceived measures of residential density, mixed-land use, and proximity to parks are associated with objective environmental measures related to physical activity. However, in Mexico, it should not be assumed that perceived measures of intersection density and proximity to transit stops are the same as objective measures. Our results are consistent with those from high-income countries in that associations between perceived and objective measures are modified by individual sociodemographic and psychosocial factors.

Introduction

Urban design and re-engineering of infrastructure are important potential strategies for promoting physical activity (PA) (1). Providing safe, attractive, and convenient settings for PA may help residents incorporate PA into their lives and meet PA recommendations (2). However, improving features of the built environment may not be sufficient to motivate residents. The decision to engage in PA may result from direct or indirect influences of the built environment and may be mediated by individual cognitive factors (3), such as people's perceptions about their environment (4).

Individuals' perceptions of the environment are measured via self-report, whereas objective measures are generally derived from data produced by geographic information systems (GIS) or street audits. Perceptions are filtered through individual standards of evaluation (5); thus, 2 individuals may perceive the same environment differently.

Studies examining the correspondence between perceived and objective measures of the built environment in high-income countries show poor to moderate agreement ($\kappa = 0.01–0.49$), and results vary by feature and setting (4,6–10). The effect of the built environment on PA may depend on the level of agreement between perceived and objective measures of the environment (11). Low correlation between objective and perceived measures of the built environment has been found among older adults (4), people who have low socioeconomic status (SES) (6), married or cohabitating adults (4), people who have children in the household (6), and those who engage in low levels of PA (10). Walking distance to the nearest supermarket is overestimated to a greater extent by men than by women (12).

In low- and middle-income countries, evidence on the correspondence between objective and perceived measures of the built environment is scarce. The aim of this study was to test the correspondence between objective and perceived measures of the built environment for PA in a representative sample of adults from Cuernavaca, Mexico, and to assess whether certain variables modify these relationships.

Methods

We conducted a cross-sectional, population-based study of adults in Cuernavaca, Mexico (population, 365,000) in 2011. A representative sample of Cuernavaca residents was selected by using census tracts as primary sampling units. Cuernavaca is divided into 123 census tracts, which were stratified into 4 levels of SES determined by the National Institute of Statistics, Geography and Informatics (INEGI) (13) and 2 levels of objectively measured walkability (14). Eight census tracts per stratum were randomly selected, yielding 32 study census tracts. Seven blocks were randomly selected per census tract and 2 to 4 households were selected per block (15).

Field workers recruited one participant per household during a home visit. Eligible participants were aged from 20 to 65 years, able to walk, and permanent residents of that household. Details on sampling strategy and data collection are available elsewhere (15). The study response rate was 58.9% (677/1,150; based on the number of selected households with an eligible adult). Of the 677 participants originally recruited, 18 had incomplete data on environmental perceptions, 6 had incomplete data on objectively measured features, and 8 did not meet accelerometry criteria, leaving 645 for analysis. The study was approved by the institutional review boards of Emory University and the Mexican National Institute of Public Health.

We used the Abbreviated Neighborhood Environment Walkability Scale (ANEWS) adapted for use in Latin America for measuring perceptions of environmental features (16). ANEWS measures perceptions of environmental features hypothesized to be related to PA, including land-use mix, intersection density, residential density, proximity to transit stops, proximity to parks, perceived neighborhood safety, and perceived park safety (as well as others that were not used in this analysis). “Land-use mix” refers to the diversity of destinations (eg, grocery stores, post offices, parks) within walking distance of a person’s residence. “Intersection density” refers to street connectivity: as density increases, more walking routes are available (with implications for increased safety) and walking for transportation becomes more interesting and efficient. “Residential density” refers to the critical mass of people: an increase in residential density increases the number of people who can be active and the opportunities for people to see others being active. Walking to and from transit stops offers an opportunity to be active. Studies demonstrate good test–retest reliability for ANEWS (intraclass correlation coefficient > 0.75) (10,17).

For objective measures of environmental features, the location of each participant was manually geocoded in ArcGIS (ESRI, Inc). We defined 500-m and 1-km street-network buffers around each participant’s residence. Similar buffers were reported to adequately capture data on perceptions among adults of neighborhood walkability (9,18,19). Data sources were provided by INEGI and the Land Use Registry Department of the City of Cuernavaca (20).

For each feature, we computed an objective variable consistent with the feature measured by ANEWS (Appendix). For example, for residential density, ANEWS asks participants about 6 types of residential buildings and then generates a residential density score based on the number of single family units per buffer area; our objective measure of residential density was a count of residential units instead of a residential density score.

Self-reported data were collected on age, sex, education level, marital status, individual SES (based on 25 questions on household features and assets used by the National Health and Nutrition Surveys of Mexico [23]), and motor vehicle ownership. Minutes per week of moderate to vigorous PA were measured with GT3X Actigraph accelerometers (ActiGraph, LLC) using 60-second epochs and scored by using the cut points for adults defined by Freedson et al (24). We obtained summary scores for perceived neighborhood safety and perceived park safety using ANEWS; these variables were dichotomized as safe or unsafe. Details are available elsewhere on how data on these variables were collected and processed (15,25).

Statistical analysis

Descriptive statistics (means, 95% confidence intervals [CIs], ranges, and percentages) were estimated for each perceived and objective variable. To test the correspondence between objective and perceived measures, we estimated Pearson correlations between continuous variables using the *corr_svy* procedure (26). Because we observed positively skewed distributions in perceived and objective measures of residential density and proximity to transit stops, we log-transformed these variables before calculating correlations.

We used multivariate regression models to estimate associations between objective and perceived measures of the built environment. Perceived residential density and proximity to transit stops were treated as natural-log-transformed variables because this parameterization provided the best fit. First, we ran unadjusted linear regression models with the perceived measure as the dependent variable and the objective measure as independent variable. Exploratory analyses suggested nonlinear relationships between all objective and perceived measures of the built environment; therefore all objective variables were introduced as quintiles (using city-wide quintiles) or 5-category variables (for proximity to parks and transit stops). Second, all covariates reported by other researchers as being correlated with objective and perceived measures of the built environment (age, sex, education level, SES, marital status, and meeting PA recommendations) (4,6,10,27) were introduced into the models. Because of high levels of crime in Cuernavaca (28), models were also adjusted for perceived safety from crime in the neighborhood (perceived park safety for the model of proximity to parks) to control for potential confounding. To test if any feature modified the relationship between perceived and objective measures, we tested for interactions between objective measures and individual variables (including perceived safety) in the adjusted models. Models were run assuming robust standard errors, tested for specification error by using the Stata *linktest* procedure, and tested for multicollinearity by exploring the variance-inflation factor. Adjusted predictions and 95% CIs evaluated at the mean of the covariates were calculated using the post estimation command *margins*. Plots of predicted values were generated with these data by using the *marginsplot* post estimation command. All analyses accounted for the complex multistage clustered design and were weighted for probability of selection. Analyses were carried out using Stata v.13.0 (StataCorp LP) survey procedures.

Results

No significant differences in sociodemographic features were found between participants originally recruited and the analytic samples. Participants were aged 42 years (95% CI, 40.7–43.2 y) on average. Of the 645 participants, 51.4% were female, 65.6% were married or cohabiting, 54.8% owned a motor vehicle, and 58.7% met the international recommendations of 150 minutes per week of moderate to vigorous PA (Table 1). Almost 95% perceived a transit stop within 10 minutes or less of walking distance, 49.1% perceived moderate intersection density, and more than 58.0% perceived having 10 or more destinations within a 10-minute walk (Table 2).

We found significant correlations between perceived and objective measures of residential density, land-use mix, proximity to parks, and proximity to transit stops ($P < .001$ for all correlations); perceptions of intersection density were not significantly correlated with objective measures (Table 3).

Unadjusted models for estimating the association between perceived and objectively measured variables showed significant relationships between categories or quintiles of objectively measured residential density, land-use mix, proximity to transit stops, and proximity to parks and their corresponding perceived variable (P value for trend across categories < .05). After adjusting for covariates, the magnitude, direction, and significance of the relationships did not change for residential density (Figure 1A), land-use mix (Figure 1B), or proximity to parks (Figure 1C). The adjusted models showed that higher quintiles of the objective variable were associated with increases in the corresponding perceived variable (P value for trend across categories < .05). However, we found no differences in perceived number of destinations or walking distance to the nearest park among the three highest categories of the corresponding objective variable (P value > .05 between each category) (Figure 1B and Figure 1C). Adjusted associations showed that the nearest parks (within a 10-min walk per the objective measure) were perceived as being farther away than they actually were, whereas the opposite was true for the farthest parks (≥30-min walk per the objective measure). The adjusted model of proximity to transit stops showed that perceived walking distances were similar for the nearest transit stops (within 5-min walk and 5–10 min walk per the objective measure) and farthest transit stops (21–30-min and >30-min walking per the objective measure); participants perceived transit stops physically located at medium distance (11–20-min walk per the objective measure) as farther away than those at the closest distance (within 5 min walk per the objective measure) (Figure 1D). No significant adjusted relationships between objective and perceived measures of intersection density were observed (Figure 1E).

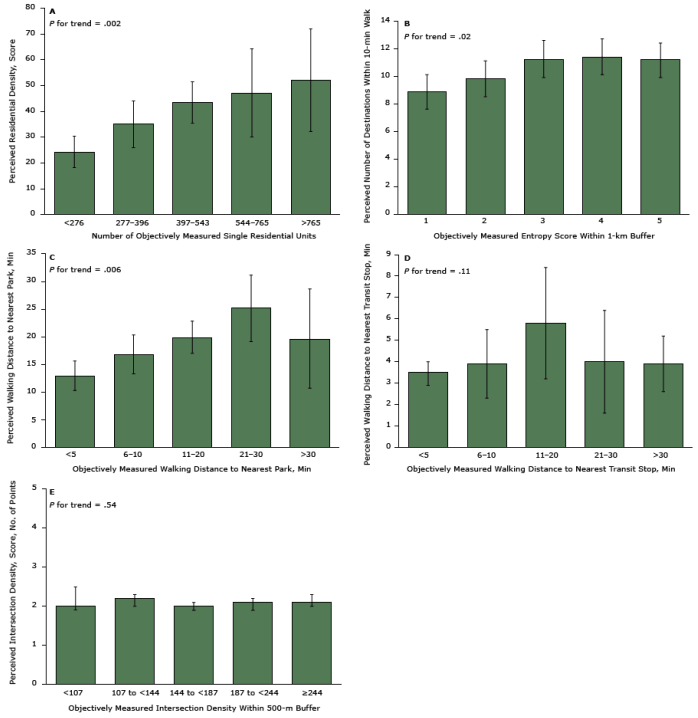

Figure 1. Associations between objectively measured and perceived measures of environmental features: A. Residential density, as determined by the number of single residential units (objectively measured) and a residential density score (perceived), calculated according to the protocol of the Abbreviated Neighborhood Environment Walkability Scale (theoretical range, 0–1,000); B. Land-use–mix, as determined by an entropy score (objectively measured) and the number of destinations within a 10-minute walk (perceived); C. Walking distance to nearest park in minutes, objectively measured and perceived (theoretical range, 2.5–35 min); D. Walking distance to nearest transit stop in minutes, objectively measured and perceived (theoretical range, 2.5–35 min); and E. Intersection density as determined by objective measurement and a score of perception (theoretical range, 1–5, based on averaged scores for Likert-scale response options of 1, strongly disagree, to 5, strongly agree to 2 statements: "There are many alternative routes for getting from place to place in my neighborhood" and "The distance between intersections in my neighborhood is usually short."). Details of measurements are provided in the Appendix. Adjusted predictions and 95% confidence intervals (CIs) were estimated after running adjusted regression models. Models were adjusted for sex, age, socioeconomic status, motor-vehicle ownership, education level, perceived safety in the neighborhood, years living in the neighborhood, and corresponding interaction terms for each calculation. Error bars are 95% CIs.

Individual features and perception of the built environment

Individual variables significantly modified the relationship between objective and perceived measures of the built environment (Figure 2). Low-SES participants reported more destinations within less than a 10-minute walk as quintiles of objectively measured land-use mix increased (P for trend across categories < .05); this trend was not observed for other levels of SES (Figure 2A). Although participants perceiving parks as safe reported longer walking distances as quintiles of objectively measured walking distances increased (P for trend across categories = .02), participants perceiving parks as unsafe reported significantly shorter walking distances for parks located 21–30 minutes or more than 30 minutes away ($P < .05$) (Figure 2B). Compared with participants who did not own a motor vehicle, participants who owned a motor vehicle reported higher residential density scores for the first 4 quintiles of objectively measured residential units (Figure 2C). Participants meeting PA recommendations reported higher residential density scores as quintiles of objectively measured residential density increased (P for trend across categories < .01); this relationship was not observed for those not meeting PA recommendations (Figure 2D). No other individual features modified the relationships between objective and perceived measures of the built environment.

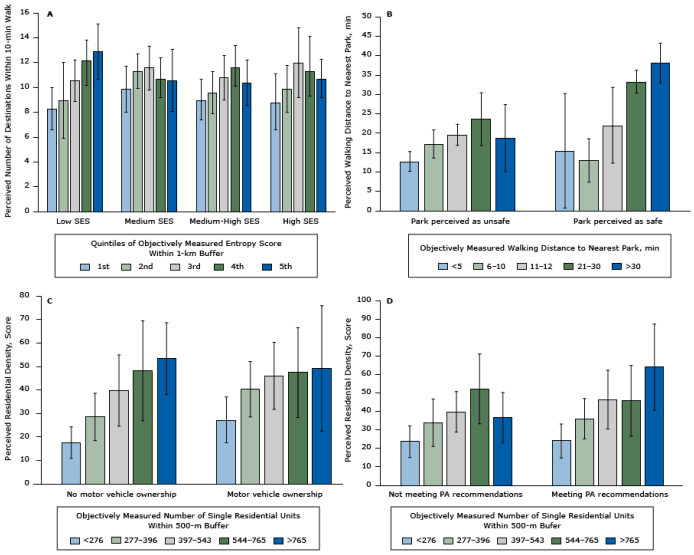

Figure 2. Individual features and perceptions of the built environment. Adjusted predictions and 95% CIs estimated after running adjusted regression models. Models were adjusted for sex, age, SES, motor-vehicle ownership, education level, perceived safety in the neighborhood, years living in the neighborhood, as well as the corresponding interaction terms for each figure. Error bars are 95% confidence intervals (CIs). Abbreviations: SES, socioeconomic status; PA, physical activity.

Discussion

We found weak correlations between objective and perceived measures of residential density, land-use mix, proximity to parks, and proximity to transit stops; perceived and objective measures of intersection density were not correlated. Adjusted associations

suggest that perceived land-use mix and proximity to parks may reach a high stable level, regardless of additional increases in the objective variable, and that perceived proximity to transit stops and intersection density were not explained by our objective measure. Our results also indicate that the relationship between objective and perceived data are neither linear nor uniform across individual or neighborhood factors. The low level of concordance between objective and perceived measures of built environment features confirm that perceptions should not be considered as proxies for objective measures.

In settings with many and varied environmental features, perceived measures may not reflect the variability of objective measures. According to a study that examined variation in the built environment by using geographic information systems in 12 countries and 15 cities, Cuernavaca has the second-highest intersection density of 15 cities (29). Cuernavaca also has a high density of transit stops (29) Although the public transportation system in Cuernavaca has official transit stops, buses stop whenever and wherever a rider signals to the driver. In this study, the difference in mean perceived walking distance between the first and fifth quintile of the corresponding objective measure was only one minute. Future studies conducted in settings where environmental features are uniformly dense are needed to confirm whether the variability of objectively measured features corresponds with participants' perceptions.

Previous reports identified groups of people in which stronger associations between perceived and objectively measured data were found (4,6,10). Inconsistencies among individual factors have been explained by the degree of environmental exposure among individuals. People who interact more with their neighborhood are hypothesized to better understand their neighborhood's characteristics. For example, active people may spend time walking in their neighborhood, which would give them a familiarity with their environment that less active people do not have (6,10). Higher levels of exposure allow people to acquire a better understanding of their surroundings and therefore provide more accurate reports. This idea is in line with our findings, which suggest that participants who meet PA recommendations and participants who did not own a motor vehicle had a better awareness of their neighborhood.

Contrary to findings of studies conducted in high-income countries, which indicate that correspondence between objective and perceived environmental features is lower among people with low SES compared with people who have higher SES (6), we found that participants who had low SES had a better awareness of neighborhood destinations than did participants who had higher SES levels. According to our results, low-SES participants reported more destinations within a 10-minute walk as quintiles of objectively measured land-use mix increased, but this trend was not observed for higher levels of SES. One possible explanation is that motivation for PA may differ between people in Mexico and people in high-income countries. Data from the IPEN (International Physical Activity and the Environment Network) adult study suggest that PA in Mexico is more strongly driven by necessity (transportation) than by choice (leisure) (15). Low-income people may be active by necessity, especially for transportation. Data on transportation for our sample suggest that low-income participants in Cuernavaca engage in approximately 100 minutes more of transportation activity than do high-income participants (A.J., D.S., M.P., unpublished data, 2016). The increased exposure to their neighborhood environment caused by active transportation may explain a better awareness of destinations among low-income participants in our study.

Likewise, participants perceiving parks as safe provided better estimates on walking distance to parks. Perceptions of certain neighborhood features, such as neighborhood cohesion, are related to better correspondence between perceived and objectively measured distance to parks (8). People probably do not often visit a park that has unattractive features, such as poor perceived safety (30), and therefore they may provide poor estimates of proximity. Participants who visit parks may not perceive them as unsafe. To understand these relationships, studies are needed on the use, perceived safety, and perceived proximity of parks. Previous studies on environmental correlates of PA among Mexican adults showed that objectively measured distance to parks was not associated with PA when parks were perceived as safe but was negatively correlated when parks where perceived as unsafe (12). In contrast, a previous analysis of our sample showed that perceived proximity to parks was the strongest correlate for PA regardless of the perception of park safety (31). Taken together, these findings suggest that perceived proximity to parks is a more proximal correlate of PA and that the way in which proximity to parks is perceived may be moderated by perceived park safety. Path analysis may be useful for testing this hypothesis (32). Future research should examine the influence of park features, park use, and park-related PA to improve strategies to increase awareness and use of parks.

This study has several limitations. Available environmental measures were not entirely comparable. Our variable for perceived land-use mix considered 23 types of destinations, whereas the entropy score is a composite of only 3 destination types. Although we confirmed the accuracy of the shapefile provided by INEGI containing the counts and locations of city parks and other destinations, the entropy score was calculated by using a land-cover land-use map instead of a parcel-level land-use map, which may have increased the inaccuracy of our measure. Additionally, informal commerce (eg, street vendors, residential space used for com-

merce) is common in Mexican cities, and data on such commercial activity are not captured by the GIS-based measure to which we had access. Associations between the objective and perceived environment depend on the congruence between neighborhood definitions. We tried to account for neighborhood size by creating variables with similar walking distances to various destinations (eg, parks, transit stops, grocery stores). Nonetheless, we could not create these variables for intersection density or residential density. For these variables, objective measures were derived by using 500-m buffers. Studies in high-income countries show that similar buffers (approximately 400 m) adequately capture data on perceptions among adults of neighborhood walkability (9,18,19). However, no evidence exists on the optimal buffer size in Latin America. Therefore, we cannot determine whether weak associations are due to a mismatch between definitions of neighborhood size or to genuine misperceptions about the neighborhood. When we tested correlations and associations using objective measures derived by using 1-km buffers, the results were similar.

This study also has strengths. It is the first study to examine the relationship between perceived and objective measures of the built environment in a middle-income country. Other strengths are our representative population; our use of cross-validated, comparable measures of perceived environmental features; and our use of objective GIS data.

We found weak correlations in Cuernavaca between perceived and objective measures of 5 environmental features related to PA in high-income countries. Our study confirms results from studies in high-income countries indicating that associations between perceived and objective measures are modified by individual sociodemographic and psychosocial factors, such as perception of safety. It provides guidance for researchers wanting to explore the environmental correlates of physical activity, suggesting that perceived measures of residential density, land-use mix, and proximity to parks may be used. However, when studying a city like Cuernavaca, researchers should not assume that perceived measures of intersection density and proximity to transit stops are the same as objective measures. In an environment in which levels of intersection density and transit-stop density are uniformly high, these variables may not be useful for understanding variability in PA.

Our results highlight the relevance of contextual factors when studying PA. Although some variables derived from research in high-income countries may be useful in understanding the environmental determinants for PA in Cuernavaca, a new set of variables consistent with the environment and culture in Mexico could better predict variability in PA. Continued research can identify such variables.

Finally, our findings also suggest that policies aimed at increasing the availability and access of neighborhood features for PA may not be sufficient to increase PA among residents (11) Complementary activities to improve perceptions of the environment should be undertaken, particularly targeted toward groups of people whose perceptions of environmental features are in least agreement with objectively measured features.

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Tables

Table 1. Sociodemographic Characteristics[a] of Mexican Adults (N = 645) Participating in Study on Features of Their Neighborhood Environment, Cuernavaca, Mexico, 2011

Variable	No. of Participants	% (95% Confidence Interval)[b]
Sex		
Female	353	51.4 (44.1–58.6)
Male	292	48.6 (41.4–55.9)
Age, y		
<35	210	33.0 (29.1–37.1)
35–50	250	38.8 (35.5–42.3)
>50	185	28.1 (24.1–32.7)
Socioeconomic status[c]		
Low	192	31.1 (23.7–39.6)
Medium	156	23.8 (20.3–27.6)
Medium-high	189	29.1 (24.3–34.4)
High	108	16.0 (12.8–19.8)
Education		
Elementary school or less	101	15.3 (12.4–18.9)
Some or complete middle school	159	25.5 (21.6–29.8)
Some or complete high school	177	26.8 (23.3–30.6)
Some or complete college	167	26.9 (23.3–30.8)
Post-graduate	41	5.5 (3.6–8.3)
Motor vehicle ownership		
No	290	45.2 (38.4–52.1)
Yes	355	54.8 (47.4–61.0)
Marital status		
Single	153	24.4 (21.3–27.8)
Married or cohabitating	421	65.6 (61.5–69.6)
Separated or divorced	54	7.5 (5.7–9.8)
Widowed	17	2.5 (1.4–4.4)
Meet physical activity recommendations[d]		
No	278	41.3 (36.7–46.1)
Yes	367	58.7 (53.9–63.3)

[a] All data based on self-report except data on meeting physical activity recommendations.
[b] Weighted for survey design. Percentages do not correspond exactly to frequencies.
[c] Categories based on 25 questions on household features and assets used by the National Health and Nutrition Surveys of Mexico (23).
[d] Minutes per week of moderate to vigorous physical activity were measured by accelerometers using 60-second epochs and were scored using the cut points for adults defined by Freedson et al (24).

Table 2. Objective and Perceived Measures[a] of Selected Features of Neighborhood Environments Among Mexican Adult Survey Participants (N = 645), Cuernavaca, Mexico, 2011

Feature	Objective Measure			Perceived Measure		
	Variable	No. of Respondents	% (95% CI)[b]	Variable	No. of Respondents	% (95% CI)[b]
Residential density	No. of residential units[c]			ANEWS residential density score[d]		
	<276	130	19.1 (11.6 to 29.8)	<14	156	24.8 (20.0 to 30.4)
	277 to 396	127	21.5 (15.8 to 28.6)	15 to 25	147	23.3 (18.0 to 29.5)
	397 to 543	130	24.6 (17.8 to 33.0)	26 to 39	99	16.0 (13.1 to 19.4)
	544 to 765	127	18.3 (11.1 to 28.7)	40 to 74	130	21.0 (15.8 to 27.5)
	>765	131	16.4 (8.9 to 28.2)	≥75	113	14.9 (10.0 to 21.7)
Intersection density	No. of ≥3-way street intersections[c]			Intersection density score[e]		
	<107	128	20.5 (13.1 to 30.5)	1	48	7.4 (5.1 to 10.8)
	107 to <144	130	20.5 (13.8 to 29.3)	1.1 to 1.5	78	11.9 (8.9 to 15.8)
	144 to <187	130	22.4 (16.1 to 29.3)	1.6 to 2.3	324	49.1 (43.5 to 54.7)
	187 to <244	128	18.4 (11.2 to 28.8)	2.4 to 3.1	185	29.9 (25.1 to 35.2)
	≥244	129	18.2 (10.4 to 30.0)	3.2 to 4	10	1.6 (0.9 to 3.0)
Land-use mix	Entropy score[f]			No. of destinations within a 10-min walk		
	<−36	126	20.5 (11.1 to 34.9)	<7	126	19.8 (14.1 to 27.2)
	−36 to <−12	129	15.5 (8.8 to 25.9)	7 to 9	138	22.2 (18.6 to 26.2)
	−12 to <2.6	129	20.5 (13.5 to 29.9)	10 to 12	137	21.6 (17.5 to 26.4)
	2.6 to <15	131	21.1 (13.6 to 31.1)	13 to 15	139	22.6 (17.3 to 29.0)
	≥15	130	22.4 (12.3 to 37.3)	≥16	105	13.8 (9.8 to 19.0)
Proximity to parks	Walking time to the nearest park, min			Walking time to the nearest park, min		
	<5	211	22.8 (13.9 to 35.1)	<5	166	27.3 (19.0 to 37.6)
	6 to 10	141	25 (16.4 to 36.1)	6 to 10	86	13.8 (10.0 to 18.7)
	11 to 20	164	32.5(20.1 to 47.9)	11 to 20	138	21.1 (16.8 to 26.2)
	21 to 30	58	10.7 (5.1 to 20.9)	21 to 30	119	19.0 (13.9 to 25.4)
	>30	71	9.1 (3.3 to 22.5)	>30	136	18.8 (12.8 to 26.9)
Proximity to transit stops	Walking time to the nearest transit stop, min			Walking time to the nearest transit stop, min		
	<5	435	65.1 (50.1 to 77.6)	<5	522	81.2 (75.5 to 85.9)
	6 to 10	109	19.2 (12.0 to 29.3)	6 to 10	90	13.7 (10.1 to 18.1)
	11 to 20	51	8.7 (3.8 to 18.7)	11 to 20	28	4.7 (3.0 to 7.3)
	21 to 30	37	4.8 (0.2 to 12.3)	21 to 30	1	0.0 (0.0 to 0.0)
	>30	21	2.3 (0.0 to 10.6)	>30	4	0.0 (0.0 to 0.1)

Abbreviations: ANEWS, Abbreviated Neighborhood Environment Walkability Scale; CI, confidence interval.
[a] See Appendix for detailed definitions of all variables.
[b] Weighted for probability of selection. Percentages do not correspond exactly to frequencies.
[c] Measure estimated within a 500-m buffer surrounding participant's home.
[d] Theoretical range 1–1,000; higher values indicate higher residential density.
[e] Theoretical range 1–4; higher values indicate higher intersection density.
[f] Higher entropy values indicate higher level of mixed-land use.

Table 3. Correlations Between Objective Measures of Selected Features of Neighborhood Environments and Perceptions About Those Features Among Mexican Adult Survey Participants (N = 645), Cuernavaca, Mexico, 2011

Built environment feature	Variable[a]	Mean[b] (Range)	ρ[c]	*P* Value
Residential density				
Objective	Number of residential units within the 500-m buffer[d]	517.7 (68.6 to 1,906.0)	0.26	<.001
Perceived	ANEWS residential density score[d]	40.8 (33.1 to 48.5)		
Intersection density				
Objective	Intersection density (3-way or more) within the 500-m buffer	170.9 (12.1 to 393.4)	0.01	.80
Perceived	ANEWS street connectivity score	2.1 (1 to 4)		
Land-use mix				
Objective	Entropy score within the 1-km buffer	1.35 (−63.4 to 67.4)	0.22	<.001
Perceived	Number of destinations within 10-min walk	10 (0 to 23)		
Proximity to parks				
Objective	Walking distance to the nearest park, min	12.8 (0.0 to 41.4)	0.19	<.001
Perceived	Walking distance to the nearest park, min	18.1 (2.5 to 35)		
Proximity to transit stops				
Objective	Walking distance to the nearest transit stop, min[d]	6.0 (0.01 to 34.3)	0.16	<.001
Perceived	Walking distance to the nearest transit stop, min[d]	3.9 (2.5 to 35)		

Abbreviations: ANEWS, Abbreviated Neighborhood Environment Walkability Scale.
[a] See Appendix for detailed definitions of all variables.
[b] Weighted for survey design.
[c] Determined by using Pearson correlations weighted for survey design.
[d] Variables were log-transformed before running Pearson correlations.

Appendix. Operationalization of Perceived and Objective Measures of Features of the Built Environment

Built environment feature	Perceived variable	Objective variable
Residential density	ANEWS asks participants to report how common were 6 types of residential buildings (from single-family residences to ≥13-story buildings) in their neighborhood. Five response options were provided, from none, coded as zero, to all, coded as 4. We calculated a residential density score using the following formula, as per the ANEWS protocol (21): single-family detached + (12 × row houses or townhouses with 1–3 stories) + (10 × apartments or condominiums with 1–3 stories) + (25 × apartments or condominiums with 4–6 stories) + (50 × apartments or condominiums with 7–12 stories) + (75 × apartments or condominiums with ≥13 stories).	We calculated the number of residential units within the 500-m buffer.
Land-use–mix	ANEWS asked participants to report time walking from home to 23 different types of nonresidential destinations: 1) convenience/small grocery store, 2) supermarket, 3) hardware store, 4) fruit/vegetable market, 5) laundry/dry cleaners, 6) clothing store, 7) post office, 8) library, 9) elementary school, 10) other schools, 11) book store, 12) fast food restaurant, 13) coffee place, 14) bank/credit union, 15) non-fast food restaurant, 16) video store, 17) pharmacy/drug store, 18) salon/barber shop, 19) participant's job or school, 20) bus or trolley stop, 21) park, 22) plaza, 23) gym or fitness facility. Response options for these items were scored according to a Likert scale as follows: 1 (1–5 min), 2 (6–10 min), 3 (11–20 min), 4 (21–30 min), and 5 (≥31 min). We calculated the number of reported destinations within a 10-minute walk (corresponding to walking approximately 1 km at 5 km/h) (22).	We calculated land-use–mix diversity by generating an entropy score within the 1-km buffer with the following formulae: $-1 \times \{[\sum(pi)(\ln pi)]/\ln k\}$, where p = proportion of total land uses, i = land use category, ln = natural logarithm, and k = number or land uses (14). Higher scores indicate higher land-use diversity.
Intersection density	ANEWS items included the following: 1) the distance between intersections in my neighborhood is usually short, 2) there are many alternative routes for getting from place to place in my neighborhood. Five response options were available, from strongly disagree, coded as 1, to strongly agree, coded as 5. These response options were recoded so that higher values indicated higher levels of intersection density. We computed the intersection density score by averaging the scores reported on the 2 items.	We estimated the number of 3-way or more street intersections per buffer area within the 500-m buffer.
Proximity to parks	We used the individual item referring to parks from the list of 23 nonresidential destinations of the ANEWS land-use–mix section. Participants reported the walking distance to the nearest park as follows: 1 (1–5 min), 2 (6–10 min), 3 (11–20 min), 4 (21–30 min), and 5 (≥31 min). We replaced response options 1, 2, 3, 4, and 5 by 2.5, 7.5 min, 15 min, 25 min, and 35 min, respectively.	We estimated the distance from the participant's home to the nearest park by using the street network. We used this information to calculate the walking time to the nearest park assuming a walking speed of 5 km/h (22). We categorized participants as follows: 1 (1–5 min), 2 (6–10 min), 3 (11–20 min), 4 (21–30 min), 5 (≥31 min).
Proximity to transit stops	We used a similar approach to the one used for perceived proximity to parks to estimate the perceived proximity to the nearest transit stop. Participant responses to the individual item referring to transit stops were operationalized in the same way as reported walking distance to the nearest park.	Distance from the participant's home to the nearest street-corner intersecting a bus route by using the street network. We calculated categories and walking time to the nearest transit stop using the same methodology that we used for proximity to parks.

Part IV. Study III. Perceived neighborhood environmental attributes associated with leisure-time and transport physical activity in Mexican adults

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Perceived neighborhood environmental attributes associated with leisure-time and transport physical activity in Mexican adults

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Abbreviations: PA=Physical activity; SES= socioeconomic status; IPEN=International Physical Activity and the Environment Network; IPAQ= International Physical Activity Questionnaire; ANEWS= Abbreviated Neighborhood Environment Walkability Scale.

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Abstract

Environmental factors have been associated with specific physical activity domains, including leisure-time and transport physical activity, in high income countries. Few studies have examined the environmental correlates for domain-specific physical activity in low-and middle-income countries, and results are inconsistent. We aimed to estimate the associations between perceived environment and self-reported leisure-time walking, moderate-to-vigorous leisure-time physical activity and transport physical activity among adults living in Cuernavaca, Mexico. A population-based study of adults 20 to 64 years old was conducted in Cuernavaca, Mexico in 2011 (n=677). Leisure and transport physical activity was measured using the International Physical Activity Questionnaire – Long Form. Perceptions of neighborhood environment were obtained by questionnaire. Hurdle regression models estimated the association between environmental perceptions and participation and time spent in each physical activity domain. High perceived aesthetics were positively correlated with participation and time spent in leisure-time walking and moderate-to-vigorous physical activity. SES differences existed for aesthetics in relation to participation in leisure-time walking. Participation in transport physical activity was positively associated with easy access to large parks, while closer distance to large parks was a negative correlate for participation and time-spent in this physical activity domain. Results suggest that perceived environmental characteristics related with physical activity are domain specific. High perceived aesthetics were an important correlate for leisure-time activities among Mexican adults, suggesting that policy strategies aimed at improving this environmental perception may be warranted. Patterns of associations between environmental correlates and transport physical activity differed from those reported in high income countries.

Keywords: Motor activity, Environment design, Space perception, Recreation, Latin America

Introduction

Non-communicable diseases constitute the leading causes of death globally, with nearly 80% of these deaths occurring in low- and middle-income countries.(2011) Since physical inactivity is a major risk factor for chronic diseases,(Lee et al., 2012) effective interventions are needed to increase population levels of physical activity (PA). (2011) Ecological models of PA emphasize the importance of considering multiple levels of influence when developing interventions.(Sallis et al., 2008) In addition to individual and interpersonal factors, certain environmental factors may be associated with specific PA domains, such as PA for leisure or transport.(Sallis et al., 2008)

Evidence suggests that the relations between neighborhood environmental attributes and PA are domain-specific.(Sugiyama et al., 2012; Van Dyck et al., 2012, 2013) While availability and access to retail and service destinations, street connectivity, residential density, and sidewalk availability have been positively related with walking for transport, (Sugiyama et al., 2012; Van Dyck et al., 2012) other features, such as availability and accessibility of recreational facilities (e.g., parks) and aesthetics, have been associated with leisure-time walking. (Sugiyama et al., 2012; Van Dyck et al., 2013) However, to date most of the available evidence on these relations is from high-income countries.

Environmental characteristics have been measured using objective and perceived (self-reported) measures.(Arango et al., 2013; Leslie et al., 2007; Salvo et al., 2014a) Perceived measures may play an important and distinct role in influencing PA, and allow for assessing relevant aspects of the built environment that are difficult to measure objectively (e.g., aesthetics and safety).(Arvidsson et al., 2012; Brownson et al., 2009) Little is known about the association between perceived environment and domain specific PA in Mexico and the Latin American region at large, and the available evidence suggests differences with findings from high income countries.(Arango et al., 2013) The objective of this study was to estimate the associations between perceived neighborhood environmental features and self-reported leisure-time walking, moderate-to-vigorous leisure-time PA, and transport PA among adults from Cuernavaca, Mexico.

Materials and methods

Study design and setting

This study was part of the International Physical Activity and the Environment Network (IPEN)–Mexico project.(Kerr et al., 2013) IPEN-Mexico is a cross-sectional, population-based study that was carried out in the city of Cuernavaca, Mexico. Cuernavaca is a city of 366 321 inhabitants in central Mexico. It has many steep slopes and has experienced an increase in crime in recent years.(Ortega, 2015) Data collection for the IPEN-Mexico study took place in 2011- 2012, and analyses are ongoing.

Neighborhood selection and recruitment.

A representative sample of adults was selected using Census tracts as sampling units. Census tracts were stratified in four levels of socioeconomic status (SES) and two levels of objectively measured walkability.(Frank et al., 2010) Eight Census tracts per stratum were randomly selected, yielding 32 (out of 123) study Census tracts. Seven blocks were randomly selected per census tract and two to four households were selected per block.(Salvo et al., 2015) Data was collected in person via two

home visits. Eligible participants were aged 20 to 65 years, able to walk, and permanent residents of that household.(Salvo et al., 2015) Participants signed informed consent forms before data collection. The study was approved by the institutional review boards of Emory University and the *Instituto Nacional de Salud Pública* of Mexico.

Physical activity

Self-reported PA was measured using the International Physical Activity Questionnaire-Long Version (IPAQ). Validation studies in Latin America suggest that the IPAQ has high reliability (Spearman's rho ~0.8) and moderate criteria validity in comparison with accelerometers.(Craig et al., 2003; Hallal et al., 2010b) The Colombian (Spanish) version of IPAQ was adapted for a Mexican audience, using culturally appropriate wording and examples. Frequency (number of days in the last seven days) and duration (minutes per day) of PA in leisure and transport PA were queried.(Hallal et al., 2010a) Only bouts of at least ten minutes were reported. Using this information, weekly minutes of leisure-time walking, leisure-time moderate-to-vigorous PA, and transport PA (walking and bicycling) were derived.(IPAQ) The proportion of participants meeting PA recommendations (150 minutes per week of moderate to vigorous PA) per PA domain was calculated. (WHO, 2010)

Perceived environment

Perceived neighborhood environment was measured using the Latin American version of the Abbreviated Neighborhood Environment Walkability Scale (ANEWS).(Salvo et al., 2014b) ANEWS consists of 58 items divided into ten subscales(Cerin et al., 2013): residential density, land use mix diversity, land use mix access, street connectivity, few cul-de sacs, no major physical barriers for walking, pedestrian infrastructure, aesthetics, traffic safety, and safety from crime. High test–retest reliability (intraclass correlation coefficient >0.75) has been reported for most of these subscales.(Leslie et al., 2005; Oyeyemi et al., 2013; Saelens et al., 2003) This version included characteristics of the built environment present in Latin American urban settings such as hilliness, proximity to public transportation, park safety, and easy access and proximity to small and large parks.(Salvo et al., 2014b) Variables were calculated as per the ANEWS protocol (Supplementary Table).(Cerin et al., 2013) All measures were scored such that higher values were expected to be positively related to PA domains.

Covariates

Self-reported sociodemographic variables including age, sex, education level, marital status, individual-level SES (based on 25 questions on household characteristics and assets (Gutierrez et al., 2012)) and motor vehicle ownership were collected.

Data analysis

Descriptive statistics (means, proportions and 95% confidence intervals) were computed for all variables. Weekly minutes of leisure-time walking, leisure-time moderate to vigorous PA, and transport PA were log-transformed to improve the normality of the distribution for the dependent variables.

All PA variables had a distribution with a large number of zeros (between 10-65% of participants did not accumulate any PA within specific domains), and a continuous right-skewed non-zero part. To account for the large number of zeros we estimated hurdle models of participation and time spent in each domain. Hurdle models recognize that decisions about PA participation are made in two steps: 1) The decision to participate in a determined PA domain (e.g. leisure-time walking), and 2) The decision on the duration of such activity, given participation. (Humphreys and Ruseski, 2015) This distinction allows factors that affect participation and factors that affect duration of PA to have different signs. (Humphreys and Ruseski, 2015) Additionally, these models may account for correlated error terms between participation and duration equations. We specified the participation decision by using a probit model and the duration decision by using a log-normal model. To account for potential correlated errors in both equations, we introduced the inverse Mills ratio in all models. Since ratios' p values were >0.05 and coefficients did not differ by introducing this ratio, we present the models assuming no correlation between error terms in equations. Based on previous reports from Mexico and other middle income countries, we adjusted models for individual variables (sex, age, marital status, SES, motor vehicle ownership, educational attainment and accelerometer wear time), and theoretically relevant environmental variables (aesthetics, safety from crime, access and proximity to large and small parks, pedestrian infrastructure, land-use mix diversity, traffic safety, and proximity to transit stops). (Arango et al., 2013; Ding et al., 2013; Ortega, 2015; Parra et al., 2011; Salvo et al., 2014a) Other environmental factors were only included in final models if associations with a p value < 0.05 were observed in single-environment (independent)-variable models, adjusting for individual variables (see above). We tested for all possible interactions between environmental variables and gender as well as SES, but only interactions with a $p<0.05$ were included in the models. The antilogarithms of the regression coefficient estimates (exp(b)) of all models were calculated and reported. All analyses accounted for the complex multistage clustered design and were weighted for probability of selection. Analyses were carried out using Stata v.14.0 (StataCorp, College Station, Texas) survey procedures (e.g. *svy*).

Results

Of the 677 participants, nine had incomplete perceived environmental data, leaving 668 participants for analysis. No differences in demographic characteristics were found between the analytic and the full sample. Among adults in Cuernavaca participants are 42.0 (95%CI: 40.7-43.2) years old on average, 51.2% are women, and 54.8% own a motorized vehicle (Table 1). Most (90.2%) participate in transport PA, whereas 34.1% and 36.6% engage in walking and MVPA during leisure-time, respectively. Overall, 46.9%, 14.1% and 30.2% meet PA recommendations through transport, leisure-time walking, or leisure-time moderate-to-vigorous PA.

Leisure-time walking

The adjusted models showed that participation in leisure-time walking was positively associated with aesthetics only among adults of low SES: Each unit increase in perceived aesthetics was associated with a 123% (43-249%) more participation in leisure-time walking. This relationship decreased in the upper three quartiles of SES (Table 2, Figure 1). Conditional on participation, duration of leisure-time walking was positively associated with aesthetics: Regardless of SES status, each unit increase in perceived aesthetics was associated with a 92% (18-213%) increase in time spent in this PA domain (Table 2).

Leisure-time moderate to vigorous physical activity

The adjusted models showed that aesthetics were associated with both participation and duration of leisure-time moderate to vigorous PA (Table 3). Each unit increase in perceived aesthetics was associated with 33% (4-70%) more participation in this domain. Conditional on participation, each unit increase in perceived neighborhood aesthetics was associated with a 67% (12-149%) increase in duration of leisure-time moderate to vigorous PA.

Transport physical activity

The adjusted models showed that participation in transport PA was negatively associated with shorter perceived walking distances to large parks (exp[B]=0.78, 95% CI= 0.63-0.97), while perceived easy access to large parks was a positive correlate (exp[B]=1.69, 95% CI=1.18, 2.41) of participation in transport PA (Table 4). Additionally, conditional on participation, duration of transport PA was negatively associated with shorter perceived walking distances to large parks: each additional unit of perceived proximity to large parks was associated with a 31% (12-46%) decrease in the time spent in this PA domain.

Discussion

Our study explored associations between perceived neighbourhood environment and domain-specific PA among adults in Cuernavaca, Mexico. Our results indicate that certain perceived environmental characteristics are correlated with some PA domains, but not with others:(Arango et al., 2013; Sugiyama et al., 2012; Van Dyck et al., 2012, 2013) While perceived aesthetics were a positive correlate for leisure-time activities, proximity and access to large parks were identified as correlates for transport PA among Mexican adults.

Aesthetics were an important correlate for participation and duration in both leisure-time activities studied (walking and moderate to vigorous PA). Previous reports on this relationship from other Latin American countries have been inconsistent.(Arango et al., 2013) Aesthetics are hypothesized to encourage engagement in leisure-time PA by providing clean and well-maintained infrastructure, attractive buildings and natural elements.(Saelens and Handy, 2008) Interestingly, aesthetics were associated with participation in leisure-time moderate-to-vigorous PA among the full sample, but only with participation in leisure-time walking among participants from the low SES. Similar SES differences have been previously reported for accelerometer based moderate-to-vigorous PA in this dataset (IPEN-Mexico).(Jauregui et al., 2015) The difference in the way aesthetics are associated with leisure time activities has two important implications. The first being that aesthetics may play a different role in deciding whether or not to engage in different types of leisure activities (i.e. walking versus moderate to vigorous). While aesthetics may not be a relevant environmental feature for walking, particularly for higher SES individuals, it may play a more relevant role for participation in moderate-to-vigorous PA. The second implication, is that low SES individuals may be more susceptible to environmental influences on PA. Since low SES Mexican adults engage in more transport activities and are therefore out in the neighborhood more often,(Salvo et al., 2015) they may be more aware of their neighborhood surroundings and therefore may be more susceptible to aesthetic influences on PA. Future studies exploring perceived aesthetics, PA domains and SES differences in Latin America and other low-to-middle income settings could help elucidate these relations. Since for now this study provides the best available evidence, improving aesthetic qualities of the built environment should be considered a potential intervention to increase PA among Mexicans. Studies conducted in high income countries suggest that aesthetic quality is linked with perceived naturalness, order and upkeep, as well as unobstructed views.(Kaplan and Kaplan, 1989; Nasar, 1994) Formative research and community-based participatory research with Mexicans are needed to identify the environmental factors that matter in PA promotion in order to improve the perceived aesthetics of a neighborhood.

The patterns of association between environmental correlates and transport PA differed from what has been reported in high income countries. (Sugiyama et al., 2012; Van Dyck et al., 2012) In Mexico, most transport PA is accounted for by walking, whereas cycling is almost inexistent. (2015; Kerr et al., 2016) Proximity to parks was a negative correlate for participation and time spent in transport PA; in contrast, access to large parks was a positive correlate for duration of this PA domain. These relations were unexpected, first because parks are generally thought to be important environmental features for leisure-time PA but not for transport PA,(Cohen et al., 2007) and second because they suggest contradictory findings. These findings could be explained in part by a lack of differentiation between leisure and transport trips among participants. Given that almost 80% of individuals reported participating in transport PA, this could be especially true for multi-purpose trips. Additionally, proximity and access to large parks may be indicative of different environmental constructs. Access to large parks was retrieved by asking participants if they could easily walk to the park. Access to large parks may be more indicative of how walkable the environment surrounding the park is, explaining the positive relation between this environmental feature and duration of transport PA. As for proximity to large parks, this variable provides information on the distance from home to the park. Large parks in Mexico generally have few access points and in some circumstances may represent a barrier to get from home to transit stops or other destinations, explaining the negative relations observed. Additionally, the negative relationship between close proximity to large parks and transport PA could be due to residual confounding. In Mexico, neighborhoods close to large parks are also those with the highest availability of public transportation. Although our models were adjusted for perceived proximity to transit stops, previous findings comparing objective and perceived measures among Mexican adults indicate that this self-reported variable is not a good proxy for its objective measure in Cuernavaca.(Jauregui et al., 2016) Future studies exploring the relationship between transport PA, access to transit, and proximity and access to large parks are needed to better elucidate these relationships.

Most of the environmental factors measured in this study were not associated with either leisure or transport PA. In contrast, previous findings evaluating associations between perceived environmental factors and accelerometer-based PA in this same population, identified more environmental correlates (e.g. safety from crime, not many cul-de-sacs) for PA.(Jauregui et al., 2015) As noted above, it is possible that environmental factors included in the questionnaire are not as relevant in low- and middle-income countries, such as Mexico. ANEWS was derived from studies conducted in high-income countries. Given the differences in urban planning and transportation systems between high- and low-to-middle income countries, developing locally-specific instruments for evaluating environmental correlates for PA is needed. Additionally,

although IPAQ is a valid and reliable instrument for PA measurement, (Craig et al., 2003; Hallal et al., 2010b) it is subject to more measurement error compared to objective measures. This might attenuate estimates on the relationship between environmental attributes and PA.(Celis-Morales et al., 2012; Nusser et al., 2012).

Limitations

This is the first study to examine perceived environmental correlates of domain-specific PA in a Mexican city and builds upon evidence from other Latin American countries. Limitations include the cross-sectional design which does not allow determination of causality. Self-report measures of environmental attributes may not accurately reflect objective measures, however they are still relevant since objective and perceived environmental attributes may be independently associated with PA.(Arvidsson et al., 2012) Additionally, for some attributes, such as aesthetics, environmental perceptions may be considered as criterion measures. (Brownson et al., 2009) The principal strengths of this study are its population representativeness, and the use of cross-validated, comparable measures of perceived environmental attributes.(Cerin et al., 2013) Advanced analytical methods were employed to examine associations, taking into account the nature of participation and duration of PA.

Conclusion

Our results suggest that perceived environmental characteristics and their relationship with PA are domain specific. High perceived aesthetics were an important correlate for leisure-time activities, suggesting that policy strategies aimed at improving this environmental perception may be warranted for enhancing leisure-time PA among Mexican adults. Patterns of associations between transport PA and environmental features differed from those reported in high income countries, underscoring the relevance of the considering contextual factors when analyzing the relationship between PA and environmental features. Future studies exploring locally-specific environmental correlates for PA are needed to better elucidate these relationships.

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Figure 1. Associations between aesthetics and participation in leisure time walking by socioeconomic status level. Cuernavaca, Mexico. 2011.

Adjusted predictions and 95% confidence intervals were estimated after running a Hurdle model. The participation equation is adjusted for sex, age, marital status, individual socioeconomic status, motor vehicle ownership, educational attainment, all perceived environment variables, the interaction term socioeconomic status quartile X aesthetics, and the survey design.

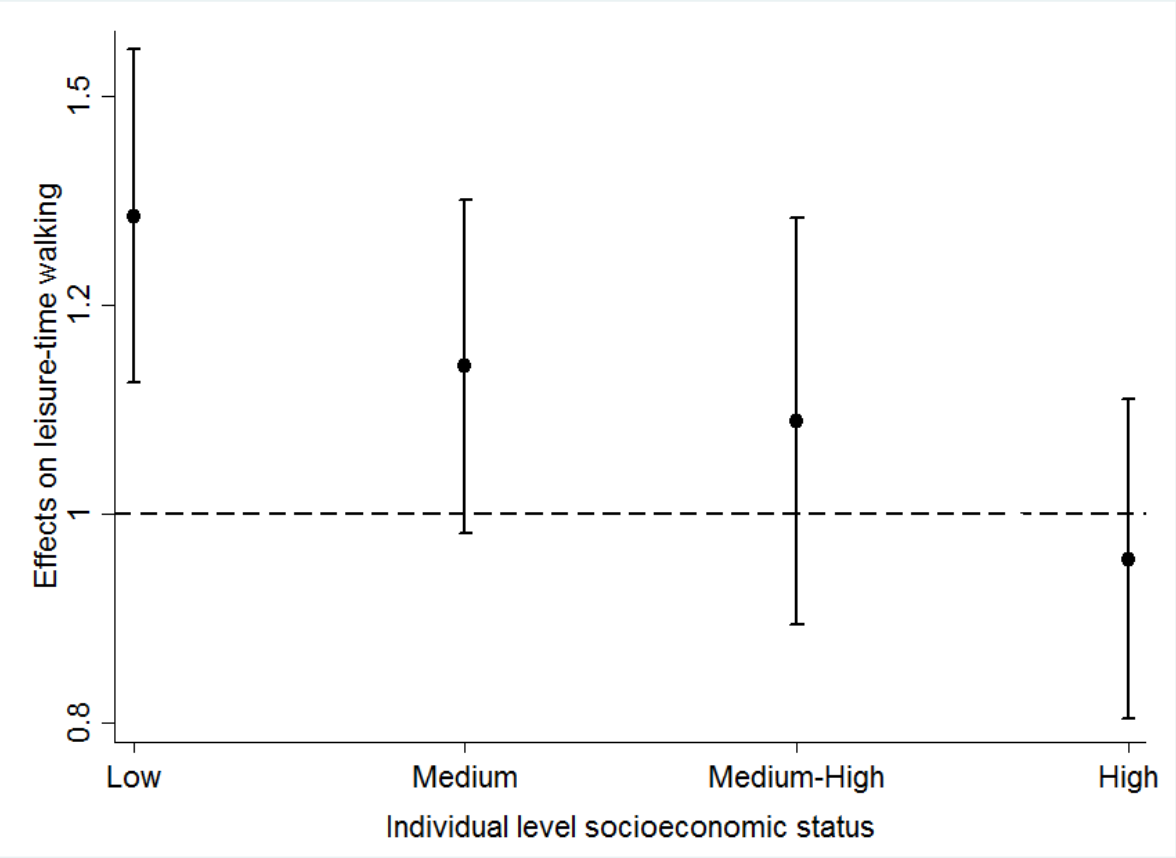

Table 1. Sample characteristics among Mexican Adults. Cuernavaca, Mexico, 2011.[a] (n=668)

Variable	n	%	95% CI
Gender (%)			
Female	366	51.2	(44.1, 58.2)
Male	302	48.8	(41.7, 55.9)
SES (%)			
Low	196	30.9	(23.7, 39.2)
Medium	163	24.0	(20.5, 27.8)
Medium-High	197	29.1	(24.5, 34.2)
High	112	16.0	(12.9, 19.7)
Education (%)			
Elementary school or less	102	15.1	(12.2, 18.6)
Some or complete Middle School	162	25.2	(21.4, 29.4)
Some or complete High School	186	27.2	(23.8, 30.9)
Some or complete College	176	27.0	(23.4, 30.9)
Post-graduate	42	5.5	(3.7, 8.2)
Motor vehicle ownership (%)			
Car	359	53.4	(46.8, 59.9)
Motorcycle	30	4.8	(3.3, 6.9)
Either	367	54.8	(48.1, 61.4)
Marital Status (%)			
Single	165	24.7	(21.9, 28.7)
Married or living with someone	430	64.4	(60.5, 69.1)
Separated or divorced	56	8.4	(5.7, 9.8)
Widower	17	2.5	(1.3, 4.3)
Meeting physical activity guidelines (%)[b]			
Transport PA	300	46.9	(44.0, 62.0)
Walking for leisure	93	14.1	(10.4, 18.9)
Leisure time MVPA	196	30.2	(25.9, 34.8)

SES= Socioeconomic Status; CI= Confidence Interval; PA= Physical activity; MVPA= Moderate to vigorous physical activity.

[a] Weighted for survey design

[b] Meeting 150 minutes per week of moderate to vigorous PA per PA domain

Table 2. Perceived environmental correlates of participation and time spent in walking for leisure among Mexican adults. Cuernavaca, Mexico, 2011. (n=668)

Environmental correlate	Participation [a,b]			Duration [a]		
	exp(B)	**exp(95% CI)**		**exp(B)**	**exp(95% CI)**	
Aesthetics [c]				**1.92**	**1.18**	**3.13**
Low SES	**2.23**	**1.43**	**3.49**			
Medium SES	1.53	0.95	2.44			
Medium-High SES	1.27	0.73	2.19			
High SES	0.89	0.58	1.36			
Land use mix diversity	1.04	0.80	1.34	1.08	0.70	1.69
Pedestrian infrastructure	0.95	0.67	1.34	1.00	0.58	1.75
Traffic safety	1.16	0.93	1.46	1.33	1.18	3.13
Safety from crime	1.02	0.88	1.18	1.02	0.92	1.92
Proximity to small parks	1.01	0.92	1.12	1.03	0.77	1.35
Park access	1.19	0.86	1.64	1.23	0.87	1.22
Proximity to large parks	0.99	0.82	1.21	0.98	0.68	2.21
Access to large parks	0.97	0.70	1.34	0.85	0.72	1.34
Proximity to transit stops	0.88	0.71	1.09	0.77	0.50	1.44

SES = Socioeconomic status; CI= Confidence Interval

[a] Regression coefficients estimated using a Hurdle model. Both equations are adjusted for sex, age, marital status, individual socioeconomic status, motor vehicle ownership, educational attainment, all perceived environment variables listed in the table and the survey design. Exp(B) is to be interpreted as the proportional increase in total minutes per week of moderate to vigorous physical activity associated with a 1 unit increase on the independent variable.

[b] Equation additionally adjusted for the interaction term SES quartile X aesthetics.

[c] Significant interaction by SES. The sliced associations are presented. See Figure 1.

Table 3. Perceived environmental correlates of participation and duration of leisure-time moderate to vigorous physical activity among Mexican adults. Cuernavaca, Mexico, 2011. (n=668)

Environmental correlate	Participation			Duration		
	exp(B)	**exp(95% CI)**		**exp(B)**	**exp(95% CI)**	
Aesthetics	**1.33**	**1.04**	**1.70**	**1.67**	**1.12**	**2.49**
Land use mix diversity	0.97	0.81	1.16	0.95	0.69	1.31
Pedestrian infrastructure	0.79	0.58	1.09	0.60	0.36	1.01
Traffic safety	1.09	0.87	1.37	1.26	0.81	1.95
Safety from crime	1.02	0.84	1.24	1.06	0.74	1.51
Proximity to small parks	1.07	0.99	1.16	1.04	0.99	1.08
Park access	0.95	0.76	1.18	0.88	0.59	1.32
Proximity to large parks	1.03	0.90	1.18	1.08	0.85	1.39
Access to large parks	1.05	0.80	1.37	1.02	0.62	1.67
Proximity to transit stops	0.86	0.69	1.083	0.69	0.45	1.05

CI= Confidence Interval

[a] Regression coefficients estimated using a Hurdle model. Both equations are adjusted for sex, age, marital status, individual socioeconomic status, motor vehicle ownership, educational attainment, all perceived environment variables listed in the table and the survey design. Exp(B) is to be interpreted as the proportional increase in total minutes per week of moderate to vigorous physical activity associated with a 1 unit increase on the independent variable.

Table 4. Perceived environmental correlates of participation and duration of transport physical activity among Mexican adults. Cuernavaca, Mexico, 2011. (n=668)

Environmental correlate	Participation			Time spent		
	exp(B)	**exp(95% CI)**		**exp(B)**	**exp(95% CI)**	
Aesthetics	1.23	0.85	1.77	1.27	0.94	1.73
Land use mix diversity	0.86	0.66	1.12	0.82	0.61	1.08
Pedestrian infrastructure	0.84	0.53	1.34	0.97	0.61	1.55
Traffic safety	0.91	0.72	1.16	1.15	0.88	1.50
Safety from crime	1.06	0.91	1.24	1.11	0.88	1.41
Proximity to small parks	1.02	0.89	1.17	1.09	0.95	1.24
Park access	0.75	0.49	1.14	0.82	0.57	1.17
Proximity to large parks	**0.78**	**0.63**	**0.97**	**0.69**	**0.54**	**0.88**
Access to large parks	**1.69**	**1.18**	**2.41**	1.41	0.89	2.22
Proximity to transit stops	1.04	0.83	1.30	0.98	0.75	1.29

CI= Confidence Interval

[a] Regression coefficients estimated using a Hurdle model. Both equations are adjusted for sex, age, marital status, individual socioeconomic status, motor vehicle ownership, educational attainment, all perceived environment variables listed in the table and the survey design. Exp(B) is to be interpreted as the proportional increase in total minutes per week of moderate to vigorous physical activity associated with a 1 unit increase on the independent variable.

Supplementary Table. Definition and operationalization of perceived environmental features using the Latin American version of the ANEWS.

ANEWS sub-scale	ANEWS items	Data operationalization
Residential density	1) How common are detached single-family residences in your neighborhood 2) How common are townhouses or row houses of 1-3 stories in your neighborhood 3) How common are apartments or condos 1-3 stories in your neighborhood 4) How common are apartments or condos 4-6 stories in your neighborhood 5) How common are apartments or condos 7-12 stories in your immediate neighborhood 6) How common are apartments or condos more than 13 stories in your immediate neighborhood Five response options were provided, from "none", coded as zero, to "all", coded as 4.	The score was computed using the following formula:[a] Single-family detached + (12 * row houses/townhouses 1-3 stories) + (10 * apts/condos 1-3 stories) + (25 * apts/condos 4-6 stories) + (50 * apts/condos 7-12 stories) + (75 * apts/condos 13+ stories).
Land use mix diversity	About how long would it take to get from your home to the nearest businesses or facilities listed below if you walked to them?: 1) Convenience/small grocery store, 2) Supermarket, 3) Hardware store, 4) Fruit/vegetable market, 5) Laundry/dry cleaners, 6) Clothing store, 7) Post office, 8) Library, 9) Elementary school, 10) Other schools, 11) Book store, 12) Fast food restaurant, 13) Coffee place, 14) Bank/credit union, 15) Non-fast food restaurant, 16) Video store, 17) Pharmacy/drug store, 18)Salon/barber shop, 19) Your job or school, 20) Bus or trolley stop, 21) Park, 22) Plaza, 23) Gym or fitness facility. Response options for these items were scored using a Likert scale as follows: 1 (1-5 min), 2 (6-10 min), 3 (11-20 min), 4 (21-30 min), and 5 (31+ min).	The score was computed by averaging the scores reported on the 23 destinations.
Land use mix access	1) Stores are within easy walking distance of my home 2) There are many places to go within easy walking distance of my home, 3) It is easy to walk to a transit stop (bus, train) from my home, Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was computed by averaging the scores reported on the three items.
Intersection density	1) The distance between intersections in my neighborhood is usually short	Response options were recoded so that higher values indicated higher

	2) There are many alternative routes for getting from place to place in my neighborhood. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	levels of intersection density. The score was computed by averaging the scores reported on the two items.
Few cul-de-sacs	1) The streets in my neighborhood do not have many dead-end streets. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was derived from reported scores on the single item.
No major barriers for walking	1) There are many obstacles (canyons/hillsides, big avenues, cul-de sacs, rivers, etc) in my neighborhood that limit the number of routes for getting from place to place. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was derived from reported scores on the single item.
Pedestrian infrastructure	1) There are sidewalks on most of the streets in my neighborhood 2) Sidewalks are separated from the road/traffic in my neighborhood by parked cars 3) There is a grass/dirt strip that separates the streets from the sidewalks in my neighborhood 4) My neighborhood streets are well lit at night. 5) There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood 6) Walkers and bikers on the streets in my neighborhood can be easily seen by people in their homes. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was computed by averaging the scores reported on the six items.
Aesthetics	1) There are trees along the streets in my neighborhood 2) There are many interesting things to look at while walking in my neighborhood 3) There are many beautiful natural sights in my neighborhood 4) There are attractive buildings/homes in my neighborhood Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	The score was computed by averaging the scores reported on the four items.
Traffic safety	1) There is so much traffic along the streets near home that it is difficult or unpleasant to walk in my neighborhood	Response options for items 1 and 3 were recoded so that higher

	2) The speed of traffic on most nearby streets is usually slow (50 km/h or less), 3) Most drivers exceed the posted limits while driving in my neighborhood. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	values indicated higher levels of traffic safety. The score was computed by averaging the scores reported on the three items.
Safety from crime	1) There is a high crime rate in my neighborhood. 2) The crime rate in my neighborhood makes it unsafe to go on walks during the day 3) The crime rate in my neighborhood makes it unsafe to go on walks at night. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	Response options were recoded so that higher values indicated higher levels of safety from crime. The score was computed by averaging the scores reported on the three items.
Hilliness	1) There are many slopes and inclines in my neighborhood streets that it is difficult to walk	The score was derived from reported scores on the single item.
Access to large and small parks	Can you easily walk to the following parks? a) Large parks b) Small parks Response options were yes or no	The access to large and small parks scores were computed separately from items a) and b), respectively.
Proximity to large parks	1) About how long would it take to get from your home to the nearest large park? Response options for these items were scored using a Likert scale as follows: 1 (1-5 min), 2 (6-10 min), 3 (11-20 min), 4 (21-30 min), and 5 (31+ min).	The score was derived from reported scores on the single item.
Proximity to small parks	1) About how long would it take to get from your home to the nearest small park? Response options for these items were scored using a Likert scale as follows: 1 (1-5 min), 2 (6-10 min), 3 (11-20 min), 4 (21-30 min), and 5 (31+ min).	The score was derived from reported scores on the single item.
Park safety from crime	1) The parks, plazas, green and recreational spaces in my neighborhood are unsafe to go during the day. 2) The parks, plazas, green and recreational spaces in my neighborhood are unsafe to go at night. Five response options were available from "strongly disagree", coded as 1, to "strongly agree", coded as 5.	Response options were recoded so that higher values indicated higher levels of park safety from crime. The score was computed by averaging the scores reported on the two items.

ANEWS: Abbreviated Neighborhood Environment Walkability Scale

[a] Source: Cerin et al, 2013.

Part V. Discussion

The results presented in the previous chapters provide valuable information for better understanding the perceived environmental correlates of physical activity, as well as the relationships between objective and perceived measures of the built environment for physical activity among Mexican adults living in Cuernavaca. In the following sections a detailed discussion on the results is provided, based on the research questions of this dissertation.

V.I. Is the perceived built environment associated with objectively measured and self-reported physical activity among adults from Cuernavaca, Mexico?

Table 2 presents the hypothesized and observed associations between perceived built environmental features and physical activity variables. Findings from these analyses support previous research reporting differences in patterns of associations of built environmental correlates and physical activity between low- and middle-income countries and high income countries.

V.I.I. The consistency of inconsistencies

The relationship between the built environment and physical activity has been extensively studied in high income countries, mainly the United States, Australia and England (5, 6, 8-10). However, as state in the introduction, the Latin America urban environment differs markedly from that found in those commonly studied high income countries (58-62). As evidence from low- and middle-income countries builds up, findings suggests that patterns of associations in these settings are different than those observed in high income countries (26). Previous analyses assessing the objectively measured environmental correlates for physical activity among Mexican (14) as well as the findings from this dissertation project support this statement.

Table 2. Hypothesized* and observed associations between perceived environmental correlates and physical activity among Mexican adults living in Cuernavaca

Perceived environmental feature	Total (accelerometer-based) MVPA		Walking for leisure		Leisure-time MVPA		Transport-related physical activity	
	Hypothesized	Observed	Hypothesized	Observed	Hypothesized	Observed	Hypothesized	Observed
Land use mix	NS (14)	NS	+ (13, 56)	NS	NS	NS	+	NS
Residential density	NS (14)	NS	+ (56)	NS	NS	NS	NS	NS
Street connectivity	NS (14)	NS	NS (56)	NS	NS	NS	+	NS
Few cul-de-sacs	NS (14)	-	NS (56)	NS	NS	NS	NS	NS
No barriers for walking	NS (56)	NS	NS (56)	NS	NS	NS	NS	NS
Pedestrian infrastructure	+ (13, 48, 49)	NS	+ (56)	NS	+(48, 49)	NS	+	NS
Traffic safety	NS (49, 56)	NS	NS (49, 56)	NS	NS (49, 56)	NS	NS	NS
Feeling safe from crime	+ (48)	**+ (Men)**	+	NS	+	NS	NS	NS
Feeling safe at parks	+ (48)	NS	+	NS	+	NS	NS	NS
Aesthetics	NS (56)	**+ (Low SES)**	NS (56)	**+**	NS (56)	**+**	NS	NS
Small parks	+ (49, 56)	**+**	+ (56)	NS	+ (56)	NS	NS	NS
Large parks	+ (49, 56)	**+**	+ (56)	NS	+ (56)	NS	NS	**+ & -**
Proximity to transit stops	- (14)	-	NS	NS	NS	NS	- (14)	NS

MVPA= Moderate to Vigorous Physical Activity; NS=Non significant. *Hypothesized associations were based in previous associations observed in this sample between objectively measured features of the built environment and accelerometer-based physical activity,(14) associations reported among Latin American populations (references are in parenthesis), as well as the environmental and social environment in Cuernavaca.

The walkability index

Studies from the United States, Europe and Australia have shown positive associations between physical activity and street connectivity, land-use mix, and residential density (5, 6, 8-10). These built environment constructs have been operationalized and combined into what is known as the 'walkability index' (5, 11). The walkability index has been found to be positively associated with physical activity in these high-income settings (5, 6, 8-10). In contrast, results from Mexico utilizing the IPEN-Mexico dataset found the objectively-derived (GIS-based) walkability index, as well as its individual components, to be negatively related to objectively-measured physical activity (14).

In contrast, the results from this dissertation project (Study I and Study III), which utilized the same dataset, showed no significant associations between the three *perceived* walkability components (street connectivity, residential density and land-use mix) and domain specific physical activity and two (residential density and land-use mix) out of the three components and accelerometer-based physical activity. As for the third component, street connectivity, this environmental construct was inversely related with accelerometer-based physical activity when operationalized as cul-de-sac density, but non-significant when operationalized as perceived intersection density. We have hypothesized that in an environment with high street connectivity and low availability of public recreation spaces such as Mexico (64), cul-de-sacs provide a safe space to engage in leisure activities. Complex relationships between walking for leisure and cul-de-sacs and street connectivity have been reported previously, highlighting the need to conduct future research examining mechanisms through which different street connectivity patterns encourage or discourage physical activity (56). The lack of association between perceived residential density and land use mix and accelerometer-based and domain-specific physical activity, suggest that these variables are not among the main drivers for physical activity among Mexicans. Inconsistencies in the observed relationships between objective (inverse relation) and perceived measures (non-significant for 2 out of the 3 walkability components) of the walkability index may also be explained by a mismatch between these environmental features. A detailed discussion on this issue is provided below (Section V.II). Taken together, these findings suggest that walkability as defined by high-income countries may not be the best measure to rate the activity-friendliness of urban Mexican settings.

Public transit

Using public transportation involves some walking or cycling from the start location to a transit stop, and from the transit stop to the end location, and therefore increases the amount of moderate physical activity accumulated by users relative to private transportation. Public transit use, as well as network distance between home and transit location, have been positively associated with physical activity in various settings, mainly high income countries (79-81). Consistent with previous reports from this dataset using objectively measured distance to transit stops (14), our results show an inverse relationship between accelerometer-based physical activity and perceived proximity to transit stops (Study I), and no association between this environmental feature and neither of the three domain specific physical activity variables, among adults from Cuernavaca, Mexico.

This inconsistency between evidence from high-income countries and Cuernavaca may be explained by the high availability of public transportation and bus stops in the city (64, 65). Perhaps, this high availability of stops reduces the chance of accumulating at least a 10 minute bout of moderate to vigorous physical activity in walking from start location to transit stop and from transit stop to end location, and explains the negative relationship observed with physical activity. Negative relationships between feeder buses and transport physical activity have been reported in Bogotá, where a similar transit system exists (82).

A potential strategy for physical activity promotion in Cuernavaca could be to designate and enforce the use of formal, well-spread bus stops. Options to reformulate the transport system in Cuernavaca have also been considered by the local government, such as introducing a Bus Rapid Transit system, redesigning the bus route distribution, or introducing intermodal stations (83-85). However, despite the political will from local authorities (84, 85), several barriers have delayed the implementation of these changes, such as the opposition from the transport union (86). These strategies have shown positive impacts in other cities, not only on physical activity (87), but also on other outcomes, such as travel time savings, reduced air pollution or improved traffic safety (88). If changes to the transportation system in the city are implemented, efforts to evaluate these "natural experiments" should be considered in order to enhance the understanding of the effects of such urban policies on physical activity (89).

V.I.II. Aesthetics, parks and crime safety as a relevant environmental features for physical activity

Opposite to associations observed in high income countries, where the U.S. walkability index (and its individual components) is considered one of the best measures to rate activity friendliness in a neighborhood, other environmental features in Cuernavaca seem more relevant for physical activity. Our results suggest that aesthetics, proximity and accessibility to parks, as well as crime safety are important environmental features for physical activity promotion in this setting.

Aesthetics

Aesthetics has been linked to increased physical activity in several high income populations (44). Although inconsistent results have been reported in Latin America (26), aesthetics seem to be a relevant factor for physical activity promotion among Mexican adults. This environmental feature was consistently associated with accelerometer-based physical activity and leisure-time walking and moderate to vigorous physical activity, being these ladder variables the with the strongest asociations.

In contrast with other environmental features, perceived aesthetics is considered to be the gold standard measure since it is complicated to quantify using objective instruments (27, 28). Improving perceived neighborhood aesthetics may be a potential strategy for increasing recreational physical activity among Mexicans, especially in low income participants. Several features have been identified as aesthetic enhancing, including perceived naturalness, order and upkeep, as well as unobstructed views (90, 91). However, most of this research is derived from high income countries. In order to improve perceived aesthetics of the environment among Mexican adults, studies are needed to identify the aesthetics factors that influence physical activity. Once these factors are identified, objective measures to quantify relevant aesthetic features can be derived and used in order to target interventions aiming to improve aesthetic features.

Parks

Previous analyses with this sample reported no association between objectively measured distance to parks and accelerometer-based physical activity when parks were perceived as safe, and an inverse association when parks where perceived as unsafe (14). Our results found that *perceived* proximity to parks is the strongest perceived built environment correlate for accelerometer-based physical activity regardless of park safety perception. Findings of Study II exploring the relationship between objective and perceived measures of the built environment provide some insight into these findings.

Participants perceiving parks as safe provided better estimates on walking distance to parks compared to those perceiving them as unsafe. Based on these results, we hypothesize that the way in which proximity to parks is perceived is modulated by park safety perception, and that perceived proximity to parks is a more proximal correlate of accelerometer-based physical activity. Future research should examine the influence of park attributes and park-use on park-related physical activity in order to improve strategies to increase awareness and use of parks.

Parks may play an important role in facilitating leisure-time physical activity since they provide places for individuals to walk or jog, and many have specific facilities for sports, exercise and other vigorous activities (92). They also provide a good space for socialization, which in Mexico and Latin America may be an important driver of physical activity (44). However, in Study III we did not find any relationships between perceived park features and self-reported walking for leisure or leisure-time MVPA. The lack of association between leisure-time activities and parks may be explained by the fact that self-reported physical activity is subject to more measurement error. Despite IPAQ being a valid and reliable instrument for physical activity measurement at the population level (93, 94), it is subject to more measurement error and variability compared to objective measures. This might attenuate estimates on the relationship between environmental attributes and IPAQ-derived physical activity (95, 96). For example, although we found positive associations between self-reported leisure-time physical activity variables and most park features, these relationships were non-significant. The higher measurement error and variability of IPAQ variables may also explain the fact that more environmental correlates were found for accelerometer-based physical activity (aesthetics, proximity to large parks, access to small parks, proximity to transit stops, few cul-de-sacs and crime safety) compared to IPAQ-derived physical activity domains (aesthetics, as well as proximity and access to large parks).

Study III also reported unexpected relationships between large parks and transport-related physical activity. We found that engagement and time-spent in this physical activity domain was negatively associated with perceived *proximity* to large parks (Retrieved by asking participants*: How much time does it take you to walk from your home to a large park?*), while time-spent in this behavior was positively related with perceived *access* to large parks (Retrieved by asking participants: *Can you easily walk to a large park?*). A suitable explanation for these contradictory findings is challenging. Although some overlap may exist between perceived access and proximity to large parks, they measure different park constructs. Although for high-income countries easy access may be indicative of proximal, in Mexico it may be other things, such as better sidewalks, safer from traffic, safer from crime, cleaner. Therefore, access to large parks may be more indicative of how walkable the

environment surrounding the park is, while proximity to large parks may provide information on the distance from home to the park. In Study III we provide a discussion on potential explanations, including the possibility of a lack of differentiation between leisure and transport activities among participants, parks being a barrier for walking for transportation (i.e., affecting street connectivity), and residual confounding derived from the lack of concordance between perceived and objective measures of proximity to transit stops (See Study II). Additionally, the social environment and quality of parks could influence the relationship between proximity to parks and transport physical activity. Future analyses using the park audits of IPEN-Mexico may help us to understand if park accessibility, equipment, aesthetics and quality explain these unexpected associations. Undoubtedly, this is a complicated relationship that requires further investigation. Nonetheless, it is worth mentioning that the way in which information is collected (e.g. the questions used to retrieve the information) is based on surveys developed in high-income countries that do not necessarily translate easily to be applied in the Mexican context. Perhaps this complicated relationship is a consequence of using poor measures or measures poorly understood by the population. Better, contextually-appropriate measures are needed to conduct better built environment and physical activity research in Latin America (97).

A potential strategy for promoting physical activity among adults in Cuernavaca could consist of increasing park safety perception and/or awareness of neighborhood parks. Such types of interventions would require a better understanding on the relationship between objective and perceived proximity to parks by park safety perception (mentioned in the following section) in order to provide an adequate intervention. Other strategies could include providing neighborhood parks in new urban developments, rehabilitating and/or repurposing public spaces and providing access for leisure physical activity, such as the *ciclovías* or free physical activity classes in public spaces (98, 99). These strategies have shown promise for increasing physical activity at a population level in Latin America (100).

Safety perception

As mentioned above, park safety perception was a relevant environmental feature in the relationship between parks and physical activity. Additionally, neighborhood safety perception was also a positive correlate for accelerometer-based physical activity among males. Broad societal factors, such as social and cultural norms as well as health, economic, educational and social situations, may influence the occurrence of crime and disorder, which in turn may increase safety concerns among the population and people's willingness and motivation to practice physical activity (101). Nonetheless,

recent review studies suggest a lack of association between physical activity and safety from crime in other settings (102, 103). Most of these studies have been cross-sectional and conducted in high income countries. In contrast, from the three prospective studies included in the most recent review (102), two reported that changes in perceived safety from crime were predictors for physical activity. Additionally, the majority of studies have been conducted in high-income countries where crime rates are lower compared to those in urban areas in low- and middle-income countries (62). A review of studies conducted in Latin America suggested that safety from crime was positively associated with leisure-time physical actiivty (26).

As mentioned before, IPEN-Mexico collected data when Cuernavaca was enduring a period of very high crime (66). Additionally, estimates from the global burden of disease study in Mexico suggest that health loss due to interpersonal violence among men has increased importantly in the past few years (104). It is possible that the positive relationship observed between perceived safety from crime and physical activity among males is valid for the crime rate perceived by the population at the time and may change as crime rate perception changes. It may be that after a given threshold of crime and violence in a setting, safety from crime starts to have a significant influence on physical activity. Actions to encourage personal mobility, reclaim public spaces and create safe and accessible parks have shown positive impacts on perceived safety from crime (105). However, a better understanding of the crime trends in Cuernavaca and Mexico, as well as gender differences in safety perception are needed in order to better target interventions.

V.II. Are objective measures of the built environment related to perceptions of the built environment from Mexican adults living in the city of Cuernavaca?

Studies conducted in high income countries have consistently found poor to moderate agreement between objective and perceived measures of the built environment, and suggest that the agreement may vary by built environment construct as well as by study setting (17, 28, 33, 39, 40, 45). To our knowledge, this is the first study to explore such relationships in a Latin American setting.

Our results provide valuable insights on the validity of five perceived environmental measures generally accepted as important correlates for physical activity in high income countries in a middle-income country. In line with previous findings (17, 28, 33, 39, 40, 45), we found weak but significant correlations between objective and perceived measures of land use mix diversity, residential density and proximity to parks. However, objective and perceived measures of street connectivity and proximity to transit stops were not significantly associated at all.

This finding is interesting since among 15 cities around the world contributing GIS-derived built environment data to the IPEN study, Cuernavaca had the highest and second highest public transit availability and intersection density, respectively (64). Perceptions of these environmental constructs were also high compared to other IPEN sites (56, 57). We hypothesized that in settings where certain urban characteristics are ubiquitous, perceived measures of these built environment constructs may not reflect the variability of objective measures. Future studies in different settings should explore this hypothesis. However, in Mexico caution should be taken when analyzing relationships between these perceived environmental features (street connectivity and proximity to transit stops) and physical activity.

Perhaps a clear example of the consequences of using these variables as proxies of objective measures are the unexpected and contradictory findings mentioned above between transport-related physical activity and proximity and access to large parks found in Study III. Although our models were adjusted for perceived proximity to transit stops, previous findings from Study II comparing objective and perceived measures among Mexican adults indicate that this self-reported variable is not a good proxy for its objective measure in Cuernavaca (106). The negative relationship between short proximity to large parks and participation and time spent in transport-related physical activity could be due to residual confounding. In Mexico neighborhoods within close proximity to large parks are also those with the highest availability of public transportation. According to our data, the mean number of available routes within the 500m-buffer surrounding participants' home (measured using Geographic Information Systems), was higher among individuals perceiving a large park within <5 minutes walking distance (7.4±6.6 routes) than those perceiving a large park within >30 min walking distance (2.1 ±0.7 routes, data not shown). In fact, when adjusting regression models for the objective number of bus routes within the 500m home-buffer, the relationships between transport-related physical activity and access and distance to parks was no longer significant. In contrast, a negative and significant relationship was observed between this objective variable and transport-related activity. Future studies exploring the pathway of relationships between objective and perceived measures of the built environment and physical activity will help elucidate these relationships.

V.III. Are associations between objective measures and perceptions of the built environment moderated by demographic characteristics?

Literature from high-income countries suggests that certain groups of people may have a better awareness of their neighborhood. It has been hypothesized that individuals who are more exposed to their neighborhood have a better understanding of their surroundings. As such, active people may

spend more time walking in their neighborhoods and may provide more accurate reports (17, 45). Our results support this hypothesis by finding better correlations between objective and perceived measures of the built environment among people meeting physical activity recommendations and with no motor vehicle ownership – the strongest inverse sociodemographic correlate of physical activity in this sample (74).

Contrary to reports in high-income countries (17, 107), we found better correlations between objective and perceived measures among low SES participants. Previous findings have explained lower awareness among this group of people by the social environment (e.g. crime insecurity) in low SES neighborhoods (17, 107). Additionally, in these studies low SES participants were also less likely to meet physical activity recommendations (17, 107), which may also explain the lower awareness of neighborhood surroundings in these populations. It has been stated that motivations for physical activity in Mexico and Latin America differ to those from high income countries, being necessity (transport activity) a stronger driver than choice (leisure activity) (74, 87, 97). Low-income people may be active by necessity, especially for transportation. Although no differences in meeting physical activity recommendations have been reported in this sample by SES level (74), our data suggests that low SES participants engage in more transport physical activity. The difference in patterns of physical activity by SES level may increase neighborhood exposure in low SES participants, and therefore explain a better awareness among this group of people.

V.IV. Strengths and limitations

An important contribution of our study was the analytical approach used for exploring environmental correlates of objectively-measured MVPA within bouts, and domain-specific physical activity. Engaging in physical activity results from a combination of biological, psychological, social and environmental factors, which ultimately lead to the decision of being physically active (4). Decisions about physical activity participation are made in two steps (108): 1) The decision to participate in a determined physical activity domain, or in other words, the adoption of a given physical activity behavior (e.g. walking for leisure), and 2) The decision on time spent participating in such activity. Therefore, physical activity variables generally show a distribution with a large number of zeroes (representing non-adopters) and a continuous right skewed non-zero part (representing duration of the given physical activity behavior among adopters). The presence of many zeros in the dependent variable can lead to a number of problems when using simple linear regression to estimate a regression model (108). Previous approaches have estimated separate regression models to identify perceived environmental variables associated with: 1) likelihood of any physical activity versus no physical

activity, and 2) the duration (minutes per week) of physical activity among the subgroup engaging in this behavior (56). However, such models may render biased estimates because of the potential correlation between the error terms of both equations (participation and duration) (108).

To account for this unusual distribution in the data and the potential correlation between the error terms, we implemented an econometric approach to analyze physical activity data. There are a number of econometric approaches to dealing with the problem of zeroes (e.g. binary response models, sample selection models, Tobit Models). A detailed explanation on such models is found elsewhere (108). Briefly, the choice of an estimation approach depends on 1) the nature of the zeroes present in the data (e.g. zeroes represent missing data vs. zeroes represent an individual choice), and 2) the nature of the decision (e.g. participation and duration decisions made simultaneously). We assumed that zeroes present in the data represented an individual choice. These type of zeroes call for either a two-part model, when the participation and duration decisions are independent, or a hurdle model, when they are related (109). Such models are useful for estimating relationships between variables for mixed discrete-continuous outcomes, while allowing separate mechanisms to determine the likelihood and duration for MVPA within bouts (109). A handful of previous reports have implemented two-part or hurdle models to identify correlates of participation and time spent in physical activity and sports among Canadian populations (108), as well as the association between physical activity and the occurrence and severity of disability (110). By implementing this statistical approach, we expanded our understanding on the environmental correlates for participation and time spent in specific physical activity behaviors.

Results of this dissertation should be interpreted in light of several limitations. Discussions on the main limitations of each study were provided in previous sections (Study I, II and III). Here, we discuss some additional general limitations that cut across the three studies that conform this dissertation project. The sampling frame of the study intended to provide a representative sample with the highest variability in terms of socioeconomic status and the walkability components (connectivity, land use mix diversity and residential density). Relationships between physical activity and these perceived environmental measures could be considered as representative among adults living in Cuernavaca. Although other environmental features were not considered in the sampling frame (e.g park availability or transit distance), we believe that the representativeness for these features is preserved based on the fact that all other objectively measured environmental constructs varied by walkability level. Finally, some environmental factors included in ANEWS are not as relevant in low- and middle-income countries, such as Mexico, as in high income countries. Given the differences in urban planning and transportation systems between high- and low-to-middle income countries (58-

61), developing locally-specific instruments for evaluating environmental correlates for physical activity is needed.

V.IV. Future research

The results of this dissertation provide relevant information to better understand the relationship between the built environment and physical activity among adults of Cuernavaca. However, several gaps in literature still remain. The individual studies provide information on future research in light of the reported results of each analysis. In this section we discuss a general view on future research lines considering the complete evidence provided by this dissertation.

Future studies should include exploring the simultaneous relationship between objective and perceived measures of the built environment with physical activity. Our data suggest that perceptions of the built environment are more proximal correlates of physical activity and that such perceptions are modified by demographic and psychosocial factors (i.e. safety perception). As mentioned before, path analyses would help elucidate such relations in order to better target interventions aiming to promote physical activity.

Our data also suggested interesting relations between perceived safety from crime, gender, and physical activity. Given the high crime situation in the city of Cuernavaca during IPEN-Mexico data collection, it is possible that these results are not be generalizable to other settings in Mexico or Latin America. It is likely that the observed relationship between safety perception and physical activity among men varies as safety perception changes. It is also possible that safety perception influences the decision to be active in different places (e.g. running on the street versus running at a park). Longitudinal studies exploring the relationship between changes in objective and perceived safety from crime, gender and physical activity are needed to better understand these relations.

Our findings also suggest that the instruments used to measure the built environment, and perhaps transport physical activity too, may not be adequate for use in Mexico. Transport related physical activity was not associated with any environmental feature but those related to parks, suggesting complicated relationships. Given that transport physical activity is a very common domain among adults in Cuernavaca and that physical activity may be driven more by necessity than by choice in this setting,(74) a better understanding on the validity of the IPAQ-long form for measuring this physical activity domain is needed. Future studies evaluating the content validity of this instrument are in order.

Finally, our results reinforce that the American definition of walkability is not appropriate to evaluate the activity friendliness of the built environment in Mexico, and that the use of some environmental measures derived from high income country-research (i.e. street connectivity and proximity to transit stops) is not adequate to capture the environmental variability for physical activity in Mexico. More studies are needed to confirm our hypothesis that in settings where environmental features are uniformly dense, participants' perceptions may not reflect the variability of objectively measured features. In contrast, other environmental features, such as the availability of parks, feeling safe from crime and aesthetics are more relevant for physical activity in this setting. Future studies should explore the environmental factors that matter for physical activity in the Mexican context. Formative and community-based research may be useful for this purpose. Partnerships with other research areas (e.g. architecture, urban planning, and transportation) should also be seeked in order to identify such factors. This information should be considered in order to develop locally specific instruments for evaluating environmental correlates for physical activity in Mexico. Ultimately, a new set of variables consistent with the environment and culture in Mexico could better predict variability in PA and used to develop the "Mexican walkability index".

V.VI. Policy implications

In spite of the limitations and cross-sectional nature of the data, IPEN-Mexico is the best available evidence of the relationship between the built environment and physical activity among Mexican adults. Since the availability of more sound studies to confirm causality will likely take more years to emerge, our data is adequate for policy recommendations.

It seems possible that if access and proximity to parks were improved, increases in physical activity could be achieved. Such interventions may be more relevant for women because they engage in significantly lower levels of physical activity than men (74), and our data suggests that parks are relevant correlates for accelerometer-based physical activity among women. The evidence analysed so far has only considered the perceived proximity, access and safety at parks, however information on park equipment, aesthetics and quality is available in this dataset. Such information should be used in order to understand if park features should be improved or if programs to promote park use should take place.

Our data also suggest that improving aesthetic qualities of the built environment should be considered a potential intervention to increase physical activity among Mexican adults of Cuernavaca. The identification of the environmental factors that matter in physical activity promotion among Mexicans should be conducted in order to design adequate interventions. Our data suggest that aesthetics may be especially relevant for physical activity promotion among low income participants. Therefore, it is important that such studies should explore differences in aesthetic appraisal by income level. Interventions considering aesthetic improvements are already taking place in the city's downtown as part of the "Ecozona" project in Cuernavaca – a program that intends to implement a low emission zone in downtown Cuernavaca by reducing car use and promoting other mobility means (63, 83). Research is in order to evaluate the perception of such changes in relation to physical activity among the population, as well as the impact on public space use and physical activity.

Our data reinforce previous reports suggesting the need to improve the transportation system in Cuernavaca (14, 63). Improvements should consider the redistribution of the transportation network in order to reduce the oversupply of public transit in specific locations (63), modernization of the bus tracking system (65), as well as the introduction of official transit stops at a reasonable distance from each other (14). The introduction of bus rapid transit may be a solution. This transportation system has proven to be associated with higher activity levels in Colombia (87). If implemented in Cuernavaca (84), efforts should take place to evaluate its impact on physical activity and other health outcomes.

Our findings also suggest that policies aimed to increase the availability and access of neighborhood features for physical activity may not be sufficient to increase physical activity among residents. Complementary activities to improve perceptions of the environment should be undertaken, particularly targeted toward groups of people whose perceptions of environmental features are in least agreement with objectively measured features.

Finally, implementation of policies and programs to improve the built environment in Cuernavaca should involve multiple ministries, sectors and research areas. For example, a liaison between public health, urban planning, and transportation is likely to facilitate the implementation of such changes by ensuring that interventions are adequate for the targeted population and context.

Part VI. Conclusions

This dissertation was designed to analyze the relationship between perceived environmental measures and physical activity, as well as to explore if perceived measures of the built environment were associated with their objective measures, and if associations differed within population sub-groups. We found that some perceived environmental features are associated with objective and self-reported physical activity, however, patterns of association differ from those reported in high-income countries.

Among Mexican adults living in Cuernavaca, perceived aesthetics, park availability, crime safety and proximity to transit stops were relevant environmental features for physical activity. However, other variables that have been consistently related with physical activity in high income countries (e.g. land use mix diversity, residential density and connectivity) were not. Our results suggest that although certain variables derived from high income country research may provide a fair understanding of the environmental determinants for physical activity among Mexican adults, a set of variables consistent with the local social, cultural and built environment would better predict variability in physical activity among Mexican adults.

Taken together, our findings highlight the relevance of contextual factors when studying physical activity and suggest the need to redefine concepts like walkability and activity-friendliness based on context. Based on our results, residential density and land-use mix are not among the variables that would go into a "Mexican walkability index", whereas variables like aesthetics, parks, safety from crime and low connectivity – particularly as operationalized by high availability of cul-de-sacs, are more relevant. More research is urgently needed from low- and middle-income countries in order to identify sets of variables consistent with the environments and cultures in these settings to better explain the complex context specific relationships between the built environment and physical activity.

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