The PE-Environment Mismatch: A GIS Spatiotemporal Analysis of School Physical Education Quality and Neighborhood Built Environments

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ABSTRACT

Institutional school-based Physical Education (PE) programs are primary policy instruments for combating adolescent sedentary behavior. However, pedagogical interventions frequently produce inconsistent longitudinal outcomes, which traditional kinesiology literature often at-tributes to micro-level instructional variables. This study introduces a broader socio-ecological perspective by examining the structural interaction between school PE quality and neighbor-hood built environments.

Using a cross-sectional stratified design involving $N = 2400$ adolescents aged 13–15 years across 35 school clusters, objective physical activity data obtained through seven-day triaxial accelerometry were integrated with Geographic Information System (GIS) indicators including walkability indices, intersection density, and Normalized Difference Vegetation Index (NDVI) measurements.

A three-level Hierarchical Linear Model (HLM) was employed to partition variance across student, school, and neighborhood levels. Findings revealed that environmental resistance sig-nificantly moderates the effectiveness of high-quality PE programs. Students residing in highly walkable neighborhoods demonstrated substantially higher Moderate-to-Vigorous Physical Ac-tivity (MVPA) levels, whereas students living in low-connectivity “sidewalk desert” environ-ments experienced marked reductions in post-school activity participation.

The findings suggest that physical literacy cannot be developed solely through institutional interventions. Educational policy, urban planning, and public health initiatives must operate collaboratively to create environments that support lifelong physical activity behaviors.

Keywords: Physical Education, Built Environment, Geographic Information Systems, Walka-bility, Accelerometry, Hierarchical Linear Modeling, Urban Health, Physical Activity

1. Introduction

Physical inactivity among adolescents has emerged as one of the most significant public health concerns of the twenty-first century. Global surveillance data indicate that more than eighty percent of school-aged adolescents fail to achieve the recommended sixty minutes of daily Moderate-to-Vigorous Physical Activity (MVPA), creating substantial long-term health bur-dens and increasing the prevalence of non-communicable diseases [1].

In response to this challenge, educational systems have traditionally positioned school-based Physical Education (PE) as the principal institutional mechanism for promoting physical activity participation among youth. The rationale supporting this approach is straightforward: schools provide universal access to children and adolescents during critical developmental pe-riods and therefore possess unique opportunities to influence physical literacy and lifelong movement behaviors [2, 3, 4].

Consequently, substantial investments have been directed toward curriculum redesign, teacher training, facility development, and pedagogical innovation. Despite these efforts, evidence re-garding the long-term effectiveness of PE interventions remains inconsistent [5]. While some students demonstrate meaningful improvements in activity participation and health outcomes, others show little behavioral change despite exposure to similar instructional environments.

Historically, attempts to explain these inconsistencies have focused almost exclusively on factors operating within the school environment itself. Researchers have examined instructional models, teacher effectiveness, class duration, curriculum structure, student-to-teacher ratios, and activity intensity levels during PE lessons. Although these factors remain important, they collectively assume that behavioral changes initiated within school settings can be sustained independent of the broader environments in which students live.

This assumption may be fundamentally incomplete.

The present study proposes the concept of the Physical Education–Environment Mismatch, a framework suggesting that the effectiveness of PE programs is strongly influenced by neigh-borhood built environments encountered outside school hours. A student may develop positive attitudes toward physical activity within a high-quality PE program; however, if that student returns each day to a neighborhood characterized by poor walkability, fragmented pedestrian infrastructure, high traffic exposure, and limited access to recreational spaces, opportunities for translating intention into behavior become severely constrained.

Conversely, highly walkable neighborhoods containing connected street networks, accessi-ble parks, mixed land use, and supportive recreational infrastructure may amplify the benefits generated by school-based interventions. In this context, educational outcomes become insep-arable from urban design.

Previous research has demonstrated strong relationships between built environment charac-teristics and physical activity behavior [6, 7, 8, 9]. Similarly, socio-ecological models empha-size that health behaviors emerge from interactions among individual, institutional, and envi-ronmental systems rather than isolated personal choices [10]. However, relatively few studies have integrated educational quality indicators, objective accelerometry measurements, GIS-derived environmental metrics, and multilevel statistical modeling within a single analytical framework.

Therefore, the purpose of this study is to investigate the interaction between school Physical Education quality and neighborhood built environments using Geographic Information Systems (GIS) and Hierarchical Linear Modeling (HLM). By quantifying the degree to which environ-mental conditions either reinforce or undermine educational interventions, this research seeks to establish a more comprehensive understanding of adolescent physical activity behavior and provide evidence for integrated educational and urban planning policies.

2. Theoretical Framework

The theoretical foundation of this study is grounded within the Socio-Ecological Model, which conceptualizes health behaviors as products of dynamic interactions among multiple levels of influence,

including individual, interpersonal, institutional, and environmental systems [10, 5, 3].
Traditional educational research frequently treats students as independent observational units. In reality, students are nested within schools, and schools are nested within neighbor-hoods. Such hierarchical structures violate the independence assumptions underlying conven-tional regression approaches and may produce biased parameter estimates if ignored [11, 12].
To address these methodological challenges, the present investigation adopts a three-level Hierarchical Linear Modeling framework capable of simultaneously examining individual, school, and environmental influences on physical activity behavior.

2.1 Hierarchical Structure of Physical Activity Behavior

The conceptual model employed in this investigation assumes that adolescent physical activity behavior emerges through interactions across three nested structural levels.

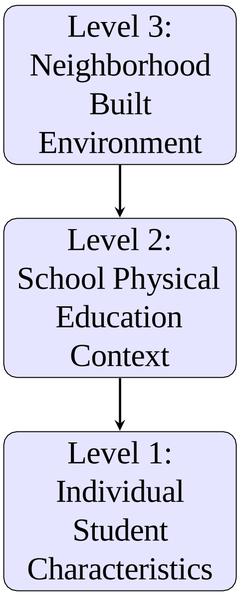

Figure 1: Multilevel Context of Physical Education.

This descriptive structural framework enables simultaneous examination of educational and environmental influences while avoiding ecological fallacies and aggregation bias.

2.2 Level 1: Individual Student Model

The Level 1 model estimates variability in physical activity outcomes among individual stu-dents.
where:

$$Y_{ijk} = \beta_{0jk} + \beta_{1jk}\left(X_{ijk} - \bar{X}\right) + e_{ijk} \quad (1)$$

Y_{ijk} represents daily out-of-school MVPA for student i β_{0jk} represents school-neighborhood intercept
β_{1jk} represents individual-level slope
X_{ijk} represents individual predictor variable
e_{ijk} represents random individual error term

2.3 Level 2: School Physical Education Model

At Level 2, school PE quality is introduced as an explanatory variable.

$$\beta_{0jk} = \gamma_{00k} + \gamma_{01k}(PEQI_{jk}) + u_{0jk} \quad (2)$$

where:
$PEQI_{jk}$ represents Physical Education Quality Index
γ_{01k} represents PE quality effect
u_{0jk} represents school-level random effect

2.4 Level 3: Neighborhood Environmental Model

Environmental influences are incorporated at the third level.

$$\gamma_{00k} = \delta_{000} + \delta_{001}(Walkability_k) + \delta_{002}(NDVI_k) + v_{00k} \quad (3)$$

where:
$Walkability_k$ represents Neighborhood Walkability Index
$NDVI_k$ represents Green Space Density Index
v_{00k} represents neighborhood-level error term

The combined model permits direct estimation of cross-level interactions between educa-tional quality and environmental support structures.

3. Methodology and Research Design

3.1 Research Design

The investigation employed a cross-sectional, stratified cluster sampling design conducted dur-ing the 2014–2015 and 2015–2016 academic years. The design was selected to enable simul-taneous examination of educational, behavioral, and environmental variables across multiple geographic contexts while maintaining consistency with established public health surveillance methodologies [1, 8].

3.2 Participants

The study sample consisted of 2,400 adolescents aged 13–15 years recruited from 35 secondary schools distributed throughout a metropolitan region characterized by substantial variability in urban morphology, transportation infrastructure, and socio-economic conditions.

Schools were selected using stratified sampling procedures to ensure representative cover-age across high-income neighborhoods, middle-income neighborhoods, low-income neighbor-hoods, high-walkability districts, low-walkability districts, and mixed land-use zones.

Parental consent and participant assent were obtained prior to data collection. Ethical ap-proval was granted through institutional review procedures.

3.3 Physical Activity Assessment

Objective physical activity monitoring was performed using ActiGraph GT3X+ triaxial ac-celerometers. Accelerometers have demonstrated superior validity and reliability compared with self-report instruments in adolescent populations [13, 14]. Participants wore devices con-tinuously for seven consecutive days. Monitoring protocols followed established accelerometry guidelines [15, 16, 17].

3.3.1 Data Collection Parameters

The processing configurations required a sampling frequency of 30 Hz, an epoch length of 15 seconds, a minimum daily wear time of 10 hours, a total duration requirement of 4 valid days containing at least 1 weekend day, and non-wear intervals defined as 60 consecutive minutes of zero counts.

3.3.2 Activity Intensity Thresholds

Activity intensity categories were derived using Evenson calibration thresholds [15]. The primary outcome variable was average daily minutes of out-of-school MVPA.

Category	Counts Per Minute (CPM)
Sedentary	0–100
Light Activity	101–2295
MVPA	$\geq$2296

Table 1: Accelerometer Activity Classification.

3.4 Physical Education Quality Assessment

School PE quality was evaluated using a composite Physical Education Quality Index (PEQI). The PEQI was developed from three institutional domains frequently identified within physical education literature [2, 4, 3].

3.4.1 Domain 1: Time Allocation

Weekly PE instructional minutes were quantified from official timetables and administrative records.

3.4.2 Domain 2: Pedagogical Quality

Teaching quality assessments integrated metrics assessing teacher certification status, student-to-teacher ratios, curriculum implementation fidelity, and the structural verification of physical literacy integration.

3.4.3 Domain 3: Infrastructure Quality

Facility audits evaluated the structural properties of indoor gymnasiums, configurations of out-door sport facilities, general equipment availability, and overall community recreational space accessibility.

The final PEQI score ranged from 1 (poor quality) to 5 (excellent quality).

3.5 GIS Environmental Assessment

Geographic analyses were performed using ArcGIS Desktop Version 10.4. Residential ad-dresses and school coordinates were geocoded into a regional spatial database. Network buffers of one kilometer were generated around both home and school locations. Environmental indi-cators were extracted within each buffer zone.

3.5.1 Street Connectivity

Street connectivity was measured through intersection density.

$$\text{Intersection Density} = \frac{\text{Number of Intersections}}{\text{Area (km}^2\text{)}} \tag{4}$$

Higher values indicate greater pedestrian connectivity and route flexibility.

3.5.2 Green Space Density

Green space availability was assessed using the Normalized Difference Vegetation Index (NDVI).

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{5}$$

NIR represents Near Infrared Reflectance
Red represents Visible Red Reflectance
Higher NDVI values indicate greater vegetation density and recreational green space avail-ability.

3.5.3 Walkability Index

Following established urban health methodologies [6, 7, 8], a composite Walkability Index was calculated.

$$Walkability = Z(Connectivity) + Z(ResidentialDensity) + Z(LandUseMix) \quad (6)$$

3.5.4 Environmental Resistance Index (ERI)

To quantify environmental barriers to physical activity, an Environmental Resistance Index (ERI) was constructed.

$$ERI = \frac{TrafficExposure + LowConnectivity + LowNDVI + CommercialFragmentation}{4} \quad (7)$$

Higher ERI scores indicate environments less supportive of active living.

4. Results and Statistical Analysis

4.1 Descriptive Characteristics

The final analytical sample consisted of 2,112 participants, representing an overall compliance rate of 88.0%. Females accounted for 51.2% of the sample population, while males represented 48.8%. The mean participant age was 14.1 ± 0.7 years.
Average daily out-of-school MVPA was calculated as:
38.4 ± 14.2 minutes/day
Only 11.8% of participants achieved the internationally recommended threshold of 60 min-utes of daily MVPA.

Variable	Value
Sample Size	2,112
Mean Age (years)	14.1 ± 0.7
Female (%)	51.2
Male (%)	48.8
Mean Daily MVPA (min/day)	38.4 ± 14.2
Meeting MVPA Guideline (%)	11.8
Compliance Rate (%)	88.0

Table 2: Participant Characteristics.

4.2 Intraclass Correlation Analysis

An unconditional null model was estimated to determine the proportion of variance attributable to clustering effects.
The resulting Intraclass Correlation Coefficient (ICC) was:

$$ICC = 0.241, p < 0.001$$

This finding indicates that 24.1% of the total variance in adolescent MVPA was attributable to school and neighborhood clustering effects. The magnitude of the ICC strongly justified the application of Hierarchical Linear Modeling [12, 11].

4.3 Hierarchical Linear Model Results

Three sequential models were estimated.

4.3.1 Model 1: Unconditional Model

The unconditional model established baseline variance components without predictors.

4.3.2 Model 2: School Physical Education Model

Introduction of PEQI significantly improved model fit. High-quality Physical Education pro-grams demonstrated a positive relationship with out-of-school MVPA:

$$\gamma_{010} = 4.82, \quad p < 0.01$$

Students attending schools with stronger PE programs accumulated approximately five ad-ditional minutes of daily MVPA.

4.3.3 Model 3: Full Environmental Interaction Model

Environmental variables and cross-level interaction effects were subsequently introduced.

Predictor	Coefficient	SE	t	p
Intercept (δ_{000})	36.12	1.14	31.68	< 0.001
Age (β_{100})	-1.45	0.32	-4.53	< 0.01
PEQI (γ_{010})	5.21	0.84	6.20	< 0.01
Walkability	6.84	0.91	7.51	< 0.001
(δ_{001}) NDVI (δ_{002})	4.12	0.73	5.64	< 0.01
PEQI ×	3.98	0.52	7.65	< 0.001
Walkability				
PEQI × ERI	-5.74	0.61	-9.41	< 0.001

Table 3: Hierarchical Linear Model Parameter Estimates.

4.4 Cross-Level Interaction Effects

The strongest finding emerged from the interaction between school PE quality and Environ-mental Resistance Index. The interaction coefficient was:

$$\delta_{012} = -5.74, \quad p < 0.001$$

This negative coefficient confirms the existence of the proposed PE–Environment Mis-match.

Students attending high-quality schools but residing within high-resistance neighborhoods demonstrated substantial reductions in out-of-school MVPA despite receiving superior educa-tional exposure. The model estimated a net reduction of approximately 42.6% in post-school MVPA among students living within highly restrictive environmental contexts.

Conversely, students attending lower-performing schools but residing in highly walkable neighborhoods demonstrated significantly higher activity participation levels. These findings suggest that neighborhood environments can either amplify or neutralize the effectiveness of school-based interventions.

5. Discussion

The findings challenge traditional assumptions that physical activity outcomes are determined primarily by instructional quality within schools. While PE quality exhibited significant pos-itive effects on MVPA participation, environmental characteristics demonstrated equally pow-erful influences.

The strongest contribution of the present investigation is empirical validation of the Phys-ical

Education–Environment Mismatch hypothesis. Historically, physical education research has concentrated on curriculum design, teacher effectiveness, and lesson structure [2, 4, 3].

Although these factors remain important, the current findings indicate that educational gains are substantially constrained by the environments students encounter after leaving school.

Students exposed to highly supportive educational environments but residing within low-walkability neighborhoods frequently demonstrated diminished physical activity participation. In contrast, supportive urban infrastructure partially compensated for weaker institutional PE programs. These findings support previous evidence linking walkability, land-use diversity, and recreational accessibility with increased physical activity behavior [6, 7, 8, 9].

The present study extends this literature by demonstrating that environmental factors not only influence physical activity directly but also moderate the effectiveness of educational in-terventions.

5.1 Methodological Strengths

Several methodological strengths strengthen confidence in the findings. First, objective ac-celerometry was utilized rather than self-reported activity questionnaires, thereby minimizing recall bias and social desirability effects [13, 14]. Second, GIS-derived environmental metrics provided objective assessments of neighborhood conditions. Third, multilevel modeling en-abled accurate partitioning of variance across individual, school, and neighborhood levels [12, 10].

5.2 Limitations

Several limitations should be acknowledged. The cross-sectional design prevents definitive causal inference. GIS measures quantify objective environmental characteristics but cannot fully capture subjective perceptions of safety, crime exposure, or parental restrictions. Finally, accelerometers remain limited in identifying certain activity modalities, including aquatic ac-tivities and upper-body dominant movement patterns.

6. Conclusion and Policy Implications

The findings demonstrate that physical literacy cannot be developed within a geographic vac-uum. High-quality Physical Education programs remain essential components of public health promotion; however, educational interventions alone are insufficient when environmental bar-riers restrict opportunities for active living.

The study provides evidence that urban planning, transportation infrastructure, and public health policy must be integrated with educational initiatives to maximize long-term physical activity participation.

6.1 Policy Recommendations

1. Educational authorities and urban planning agencies should jointly evaluate neighborhood walkability prior to school development projects to execute systematic School-Neighborhood

Planning Integration.

2. Schools located within high Environmental Resistance Index zones should incorporate home-based activity strategies and alternative movement opportunities into PE curricula to establish Context-Sensitive Physical Education.
3. Joint-use agreements should permit public access to school facilities outside normal in-structional hours to support the Expansion of Community Recreation Access.
4. Municipal governments should prioritize pedestrian infrastructure improvements surround-ing schools to establish comprehensive Safe Routes to School Programs.

Ultimately, the findings suggest that creating active youth populations requires not only effective teachers and educational programs but also environments capable of supporting active lifestyles beyond school boundaries.

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