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Life stage- and sex-specificity in relationships between the built and socioeconomic environments and physical activity

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Abstract

Background—In the largely cross-sectional literature, built environment characteristics such as walkability and recreation centers are variably related to physical activity. Subgroup-specific effects could help explain inconsistent findings, yet few studies have compared built environment associations by key characteristics such as sex or life stage.

Methods—Using data from the National Longitudinal Study of Adolescent Health (Wave I, 1994–95; Wave III, 2001–02; n=12,701) and a linked geographic information system, we estimated cross-sectional relationships between moderate to vigorous physical activity (MVPA) bouts and built and socioeconomic environment measures. Negative binomial generalized estimating equations modeled MVPA as a function of log-transformed environment measures, controlling for individual sociodemographics and testing for interactions with sex and life stage (Wave I and III, when respondents were adolescents and young adults, respectively).

Results—Higher landscape diversity [coeff (95% CI): 0.040 (0.019, 0.062)] and lower crime [coeff (95% CI): −0.047 (−0.071, −0.022)] were related to greater weekly MVPA regardless of sex or life stage. Higher street connectivity was marginally related to lower MVPA [coeff (95% CI): −0.176 (−0.357, 0.005)] in females but not males. Pay facilities and public facilities per 10,000 population and median household income were unrelated to MVPA.

Conclusions—Similar relationships between higher MVPA and higher landscape diversity and lower crime rate across sex and life stage suggest that application of these environment features may benefit broad populations. Sex-specific associations for street connectivity may partially account for variation in findings across studies and have implications for targeting physical activity promotion strategies.

(MeSH*)

Environment design; * physical activity; * adolescent; * epidemiology; * United States

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INTRODUCTION

There is growing evidence that built environment characteristics such as walkability and recreation centers are related to physical activity, yet study findings are inconsistent.[1–3] Differences in study populations, particularly by age and sex, may be one source of variation in study findings. Understanding such variation is critical for identifying key mediators for different subgroups and targeting and tailoring physical activity promotion policy strategies. Yet, research examining age and sex differences using comparable environment and behavior measures and study design is scant.

Social and other determinants of physical activity exhibit sex differences,[4] which may be more pronounced in adolescence, when participation in organized physical activity is higher in males.[5] Safety concerns [6] and sociodemographic characteristics [4] may be more influential in females than males. Other than a handful of studies reporting differences in built environment-physical activity [7–11] or obesity [9,12] associations by sex, few studies have examined sex-specific associations.

Further, physical activity declines dramatically from adolescence to young adulthood,[13,14] perhaps due to shifts from structured sports (e.g., sports teams) and social activities (e.g., skateboarding [15]) into individual activities.[16,17] Individual and environmental barriers and facilitators to physical activity [18] likely differ by age. Indeed, while largely adult-based literature shows lower physical activity in areas of greater urban sprawl,[19,20] Nelson and colleagues found higher physical activity in adolescents living in suburban areas [21] characterized by reduced traffic, which is a strong barrier for parental encouragement of physical activity.[22]

In this study, we take advantage of a large longitudinal cohort to estimate and compare cross-sectional relationships between moderate to vigorous physical activity (MVPA) and several built and socioeconomic environment characteristics by sex and across two life stages – adolescence and young adulthood – of critical relevance for weight gain and physical activity declines.[23,24] Comparing associations in the same individuals measured as adolescents and later as young adults helps to address unmeasured determinants of MVPA that vary systematically among cohorts. By informing how consistent built environment associations are across subgroups, findings can ultimately guide built environment-related physical activity promotion policies, help explain inconsistent study findings in the current literature, and reduce unexplained variability and bias in analysis in future studies.

METHODS

Study population and data sources

We used Wave I (1994–95) and III (2001–02) data from The National Longitudinal Study of Adolescent Health (Add Health), a cohort study of 20,745 adolescents (Wave I) representative of the U.S. school-based population in grades 7 to 12 (11–22 years of age) in 1994–95 followed into young adulthood (Wave III). Add Health included a probability sample [assigned sample weights for national representation (n=18,924 in Wave I, 14,322 in Wave III)] plus subsamples of selected minority and other groupings collected under protocols approved by the Institutional Review Board at the University of North Carolina at Chapel Hill. The survey design and sampling frame have been discussed elsewhere.[25]

Using a Geographic Information System (GIS), we linked community-level data to Add Health respondent residential locations in Wave I (geocoding match statistics published elsewhere [26]) and Wave III; community-level data were time-varying, reflecting data matched to the year of interview. Residential locations were obtained from geocoded home addresses with street-segment matches (n=12,263), global positioning system (GPS) measurements (n=1,148), or ZIP/ZIP+4/ZIP+2 centroid match (n=647) among Wave III respondents in the probability sample. Differences in individual-level and environmental measures across location sources were consistent with greater reliance on GPS or ZIP codes (compared to geocodes) among rural respondents, who often use Post Office Boxes or other addresses that could not be geocoded. Residential locations in Wave I generally reflected family residences as adolescents, and in Wave III reflected the respondents' residence as a young adult; 68.6% of the analytical sample moved between Waves I and III. Residential locations were linked to attributes of circular areas within 1, 3, 5, and 8 kilometers (k) of each wave-specific respondent residence (Euclidean neighborhood buffer) and block group, tract, and county attributes from time-matched U.S. Census and other federal sources, which were merged with individual-level Add Health interview responses.

Of 18,924 Wave I respondents in the probability sample, 6% refused participation and 19% could not be located or were unable to participate for other reasons, leaving 14,322 Wave III respondents. Exclusions included mobility disability (n=87) or self-reported pregnancy at Wave I or III (n=578) and Native Americans due to small sample size (n=121). Of the remaining sample (n=13,546), those missing individual-level variables (n=266), environmental variables (n=568), or both (n=11) were excluded. Those excluded due to missing data (n=845; 6.2%) were similar to the analytical sample (n=12,701) with regard to Wave I and III individual sociodemographics, MVPA, and environmental variables; exceptions were lower census tract-level median income and Wave III landscape diversity, and higher Wave III MVPA in excluded respondents (data not shown). Complete case analysis is unlikely to bias estimates due to the small proportion of missing data.[27]

Study variables

GIS-derived environmental characteristics—We examined variables calculated within neighborhoods (e.g., 1 or 3k buffer, or census tracts) consistent with the strongest associations with MVPA and shown to adequately represent multidimensional environmental constructs.[26] Detailed variable definitions have been described previously.[26]

Population counts within 3k buffers were calculated by averaging census block-group population counts, weighted according to the proportion of block-group area captured within 3k. Physical activity facilities were obtained from a commercial dataset of U.S. businesses (Wave 1: 1995, Wave III: 2001) validated against a field-based census.[28] Facilities were classified according to 8-digit Standard Industrial Classification codes, including: (1) pay facilities (e.g., member, instruction, public fee) and (2) public facilities (e.g., no-cost tennis courts or recreation centers), which represented distinct constructs in prior analysis.[26] Counts of (1) pay facilities and (2) public facilities within 3k were divided by population count/10,000 to obtain *density of pay* and *public facilities*.

Simpson's Diversity Index, an indicator of *landscape diversity* and complexity,[29] was calculated within 1k using Fragstats software [30] from the U.S. Geological Service's National Land Cover Dataset [31] (Wave I: 1992, Wave III: 2001). Simpson's Diversity Index represents the probability that any two randomly selected pixels (each with a spatial resolution of 30 meters) are different land patch types (water or ice; low and medium density developed; high density developed; recreational developed; undeveloped/natural; agricultural); in other words, high values represent more varied land use, an indicator of activity-supporting environments.[32] Alpha index calculated within 1k from StreetMap 2000 files indicated the degree of *street connectivity*,[33] which provides numerous, often more direct route options, an indicator of walkability.[1]

The socioeconomic environment was represented by census tract-level *median household income* (U.S. census, Wave I: 1990, inflated to 2000 dollars using the Consumer Price Index; Wave III: 2000), and county-level *non-violent and violent crime rate* per 100,000 population obtained from Uniform Crime Reporting data (Wave I: 1995, Wave III: 2001).

Individual-level self-reported behaviors and sociodemographics—Weekly frequency (bouts) of leisure MVPA (skating & cycling, exercise, and active sports) was ascertained at Waves I and III using a standard, interview administered activity recall based on questionnaires validated in other epidemiologic studies [34]. The Wave III questionnaire was modified to include age-appropriate activities, so Wave III bouts were scaled for comparability with Wave I.[35]

Individual-level sociodemographic control variables included Wave I self-identified race (white, black, Asian, Hispanic), parent-reported annual household income and highest education attained (<high school, high school or GED, some college, college degree), and administratively determined U.S. region (West, Midwest, South, and Northeast); and age at Wave I and III interviews. Socioeconomic position in young adulthood can be characterized by a complex array of behaviors and achievements,[36,37] so we used parent income and education to indicate socioeconomic position in both waves.

Statistical analysis

Descriptive analysis—Adolescence and young adulthood (life stage) were indicated by study wave (Wave I and III, respectively). All individual-level variables were compared by sex; environment variables and individual-level variables which changed over time (MVPA and age) were compared by life stage (study Wave) using adjusted Wald tests and design-based F-tests (95% confidence level) for continuous and categorical variables, respectively, using Stata 10.1. To address skewness of environmental variables, we report median and interquartile range and performed statistical tests on natural-log transformed pay and public facilities counts and median household income. We report descriptive statistics for environment variables for males and females combined because environmental variables did not vary by sex (p>0.05), except for median household income in Wave III (females: $41.0k, males: $40.1k, p=0.03). All statistical analyses were weighted for national representation and corrected for complex survey design.

Multivariate regression analysis—We used generalized estimating equations (GEE; SAS 9.1) to estimate relationships between built and SES environment variables and MVPA bouts. MVPA followed a negative binomial rather than the more commonly used Poisson distribution (alpha>0, p<0.05); we specified a negative binomial distribution with log link function and an exchangeable correlation structure. Models controlled for Wave I race, highest parental education, household income, and region and wave-specific age. Using a backward elimination strategy, we tested and retained significant (Wald p<0.10) 3- and 2-way interactions among sex, life stage, and each independent variable. We report cross-sectional associations comparable with other studies, estimated from wave-stratified negative binomial regression models (Stata 10.1) in Appendix A; control variables and tests for sex interactions were analogous to our GEE analysis.

Buffer-based environment measures were individual-level variables. While census tracts or counties could comprise a third level in multi-level analysis, they are not nested within schools, our primary sampling unit and more important source of clustering. Additionally, multi-level analysis of unbalanced, sparse data within census tracts can result in biased estimates.[38]

Based on graphical examination and testing of quadratic and cubic terms (90% Wald confidence level) of each environment variable in fully adjusted regression models, we applied natural-log transformations to the environment measures in order to linearize relationships between each environmental variable and MVPA and reduce the influence of upper tail values. Additionally, the negative binomial model uses a natural-log link function. Because both the dependent and independent variables were logged, the,model coefficients can be interpreted as elasticities, or the percent change in MVPA predicted from a 1% change in the independent variable.

RESULTS

Individual-level characteristics are presented in Table 1. Our national dataset provided substantial variability in SES and built environment variables at both waves (Table 2). Density of pay and public facilities were significantly higher, while crime was significantly lower in young adult compared to adolescent residential locations. 5.9% (SE 0.6%) of adolescents moved to a different region in young adulthood.

In multivariate analysis, every 1% greater landscape diversity was related to 0.04% additional MVPA bouts (elasticity=0.040) (Table 3). MVPA was lower with higher crime. In females only, the association between street connectivity and MVPA was negative but not significant. Density of pay and public facilities, median household income, and, in males, street connectivity were unrelated to MVPA. With the exception of street connectivity, sex and life stage interactions were not statistically significant and excluded from the model.

DISCUSSION

We examined cross-sectional sex-specific associations between several built and SES environment characteristics and MVPA in the same individuals measured at adolescence and young adulthood using an exceptionally sociodemographically and geographically diverse longitudinal dataset. Landscape diversity and crime were related to MVPA in the expected directions. While street connectivity was differentially associated with MVPA by sex, all other associations were consistent across sex and life stage. We discuss potential explanations and implications for subgroup consistencies and differences in the following sections.

Associations consistent across subgroups

MVPA bouts were greater in those living in areas with higher landscape diversity and lower crime rate, regardless of sex and life stage. Lack of subgroup-specific associations may explain relatively consistent associations between physical activity and land use mix [9,19] and various land cover metrics,[39,40] which may be reflected in our landscape diversity measure, in existing literature. However, all associations were relatively weak (elasticities < ±0.2, generally <±0.05); specifically, a 50% increase in landscape diversity (equivalent to approximately the 75th versus 25th percentile) was associated with only 1.7% greater MVPA bouts. Additionally, better characterization of specific features related to greater MVPA is needed. Nevertheless, the consistency of these findings with prior research and among subgroups suggests that intermixing different uses of land (e.g., recreational space, low or high density development) is potentially valuable to health at the population level.

While prior research suggests that safety concerns may influence females more than males, [6,41] we found that MVPA was similarly related to crime in males and females. However, objectively measured crime [42,43] is less studied, and research incorporating complex interactions among perceived safety, objective crime, and other environment and individual factors is needed. In contrast to existing research,[44,45] median household income was unrelated to MVPA, perhaps because we examined it simultaneously with crime.

There was no association between density of pay or public facilities and MVPA for males or females, at either life stage. In contrast, Diez Roux and colleagues also examined population-adjusted resource counts, finding that physical activity was related to fee, but not nonfee, physical activity resources.[46] Despite importance for related policy strategies, few other studies have examined pay and public facilities separately, warranting replication of these analyses in other populations.

Additionally, pay and public facilities may support specific types of physical activity not distinguished by our total leisure time MVPA measure. Similarly, if crime influences particular types of MVPA or specific environment features support specific types of MVPA differently in adolescents versus young adults (e.g., recreation centers as a support for sports, which are more common in adolescents), our MVPA measure could also have masked expected sex and life stage differences. Clearly, research comparing behavior specific effects [47] across subgroups is needed.

Possible mechanisms for sex-specific associations

Higher street connectivity was associated with fewer (marginally significant) MVPA bouts in females, but unrelated to MVPA in males. Such sex differences in how street connectivity relates to MVPA could reflect “true” effect modification (differences in facilitators and barriers to MVPA across subgroups). For example, a potential source of effect modification is heavy traffic, which may be common in dense, gridded street networks and could be a more important barrier to MVPA in adolescent females than males. Alternatively, sex interactions could result from differential measurement bias by sex; that is, our MVPA measure may more completely capture skateboarding [15] or other outdoor [48] street-based activities more common in males than females. It is possible that sex differences observed in our study could be spurious and should be tested further in other populations.

Implications for policy and research

Consistent associations between MVPA and landscape diversity and crime rate across life stage and sex suggest that corresponding neighborhood-level modifications may benefit diverse populations. Including a greater variety of land uses, such as integration of greenspace or commercial uses into residential areas, may potentially facilitate increases in physical activity in diverse communities. Further, provision of safe places to be active may support physical activity in females as well as males.

Sex-specific differences in impacts of environmental factors have implications for targeting modifications and addressing existing disparities in physical activity. For example, an increase in street connectivity supported by prior research could, if our observed associations are causal, widen existing sex disparities in physical activity.[13,49] Furthermore, incorporation of important effect modifiers in research can reduce unexplained variation, improving accuracy and precision of estimated effects of the environment on physical activity. This is particularly important for associations between environment characteristics and physical activity and health outcomes, which are relatively weak and thus sensitive to small amounts of bias.

Examination of other potential effect modifiers such as individual and area-level socioeconomic position and urbanicity may further inform policy and improve research but often involve dynamic relationships between individual- and neighborhood-level factors. For example, conditioning on (adjustment for or stratification by) urbanicity is complex, as selection into an urban or nonurban area may be influenced by factors related to both the environment measures of interest and physical activity.[50] Also needed is development of a stronger causal framework for neighborhood health research [51] to better understand potential mechanisms of neighborhood environment effects and corresponding effect modification.

Strengths and limitations

Our study estimated cross-sectional associations, and was thus particularly vulnerable to measurement bias or differences in residential selection decisions, a key concern in built environment research.[52,53] However, knowledge about lifestage-specific cross-sectional associations gained from this study can be applied to future longitudinal studies. Second, changes in socioeconomic environment variables around a given location may have resulted from shifts in census boundaries between 1990 and 2000. Third, loss to follow-up and missing data could have led to biased estimates. Fourth, natural-log transformation linearized the relationships and reduced the influence of large values of environment measures, but extreme values may represent rare but important environments worthy of closer examination. Fifth, while our longitudinal data is a strength, it is possible that data collected in 1994–95 and 2000–01 may capture physical activity promotion efforts and other secular trends in recent decades that altered how environment characteristics relate to physical activity in the total population and across population subgroups. We also do not address how environment characteristics might influence individuals after moving to different broad contexts (e.g., different regions or cities), although 94% moved within the same region.

Despite these limitations, our study captures residential locations of a large, nationally representative population followed over time, enabling us to examine sex-specific relationships in the same individuals as adolescents and young adults, heretofore unaddressed in the literature. Additionally, we addressed environmental confounders while avoiding collinearity by including six built and socioeconomic environment measures shown to adequately represent key environmental constructs.[26]

Conclusions

Our findings suggest that higher landscape diversity and lower crime rates are related to greater MVPA bouts across sex and life stage. In contrast, higher street connectivity was related to lower MVPA in females but not males, with implications for future study design and development of policy strategies. Replication of our findings in other populations, examination of other potential effect modifiers, and investigation of potential mechanisms of effect modification can strengthen the scientific evidence base for built environment modifications.

What is already known

- Land use diversity, physical activity resources, and street connectivity are associated with physical activity in many studies, but results are largely inconsistent.
- Subgroup-specific effects are one possible explanation for inconsistencies in study findings.
- Few studies have examined potential sex-specific associations, and no studies have compared associations between adolescents and young adults using comparable measures and analysis.

What this paper adds

- Our findings suggest that associations between more frequent physical activity bouts and higher landscape diversity and lower crime rate are consistent in males and females and in adolescents and young adults, while street connectivity was differentially related to physical activity by sex.
- Sex is a potentially important effect modifiers that should be incorporated into analysis in order to achieve more precise and accurate effect estimates, and recognized in targeting and tailoring policy strategies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Individual-level characteristics in the same individuals measured during adolescence and young adulthood: descriptive statistics [mean/% (SE)]†

	Male (n=6242)	**Female (n=6459)**
MVPA - adolescence (mean, bouts/week)*	7.2 (0.1)	5.7 (0.1)
MVPA - young adulthood (mean, bouts/week)*	3.2 (0.1)	2.5 (0.1)
Age adolescence (mean)*	15.5 (0.1)	15.3 (0.1)
Age young adulthood (mean)*	21.9 (0.1)	21.7 (0.1)
Household income adolescence (mean, in 10,000's)	43.1 (1.5)	44.6 (1.6)
Race (%)		
White	68.4 (2.9)	69.9 (2.9)
Black	15.5 (2.1)	14.9 (2.0)
Asian	3.7 (0.7)	3.3 (0.7)
Hispanic	12.4 (1.8)	11.9 (1.8)
Highest parental education (%)		
<High school	14.7 (1.4)	15.2 (1.4)
High school/GED	31.4 (1.3)	32.3 (1.3)
Some college	28.6 (1.0)	27.0 (0.9)
College or greater	25.3 (1.7)	25.5 (1.7)

*Statistically significant difference between males and females within wave, and between wave within sex ($p<0.05$)

†National Longitudinal Study of Adolescent Health Waves I (adolescence; 1994–95) and III (young adulthood; 2001–02)

MVPA, moderate to vigorous physical activity, bouts/week

GED, Graduate Equivalency Degree

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Table 2

Built and SES environment characteristics in the same individuals measured during adolescence and young adulthood: descriptive statistics[†]

		Adolescence		Young Adulthood	
	Geographic area[‡]	**mean/% (SE)**	**median (25th, 75th %ile)**	**mean/% (SE)**	**median (25th, 75th %ile)**
Landscape diversity	1k	0.53 (0.01)	0.58 (0.44, 0.67)	0.51 (0.01)	0.54 (0.41, 0.65)
Pay facilities density (count/10k population)[*]	3k	2.57 (0.21)	1.68 (0.00, 3.62)	4.60 (0.18)	3.63 (1.70, 5.97)
Public facilities density (count/10k population)[*]	3k	0.29 (0.04)	0.00 (0.00, 0.29)	0.57 (0.04)	0.24 (0.00, 0.70)
Street connectivity	1k	0.32 (0.01)	0.30 (0.22, 0.38)	0.31 (0.01)	0.29 (0.22, 0.36)
Median household income[′]	CT	3.96 (0.12)	3.79 (2.77, 4.81)	4.06 (0.07)	3.80 (2.90, 4.91)
Crime (per 100,000 population)	Co	5,377 (238)	5,495 (3,295, 6,975)	4,724 (166)	4,383 (2,833, 6,025)
Region (%)					
West		16.0 (1.4)		16.7 (1.3)	
Midwest		31.5 (2.4)		29.9 (2.1)	
South		38.0 (1.7)		39.5 (1.5)	
Northeast		14.5 (0.8)		13.9 (0.7)	

[*] Statistically significant difference between Wave I and III

[†] National Longitudinal Study of Adolescent Health Waves I (adolescence; 1994–95) and III (young adulthood; 2001–02), n=12,701. Wave I and III measures were compared using the adjusted Wald test, corrected for clustering and weighted for representation; statistical tests were performed on lntransformed pay facilities, public facilities, and median household income to correct for skewness.

[‡] 1k, 3k=radius of Euclidean neighborhood buffer; CT=Census Tract; Co=County

[′] In 10,000’s

Table 3

Multivariate associations between built and SES environment characteristics and MVPA in the same individuals measured during adolescence and young adulthood†

	coefficient (95% CI)
Landscape diversity	**0.040 (0.019, 0.062)***
Pay facilities density (count/10k population)	−0.001 (−0.018, 0.016)
Public facilities density (count/10k population)	0.019 (−0.017, 0.054)
Street connectivity**	
Males	0.018 (−0.119, 0.154)
Females	−0.176 (−0.357, 0.005)
Median household income^	0.009 (−0.026, 0.043)
Crime (per 100,000 population)	**−0.047 (−0.071, −0.022)***

*Statistically significant ($p<0.05$)

**Statistically significant interaction with sex ($p=0.09$)

†National Longitudinal Study of Adolescent Health Waves I (adolescence; 1994–95) and III (young adulthood; 2001–02), n=12,701. Estimated using generalized estimating equations modeling MVPA as a function of ln-transformed environmental measures, corrected for clustering and weighted for representation. 2- and 3-way interactions among life stage (Wave), sex, and each independent variable was tested; only significant ($p<0.10$) interactions were retained. Adjusted for sex, age, race, household income, highest parental education, and region; and 2- and 3-way interactions between sex, life stage, and each control variable. Coefficients can be interpreted as elasticities.

MVPA, moderate to vigorous physical activity, bouts/week