Relationship Between Urban Sprawl and Weight of United States Youth

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Background: Among United States youth there is an obesity epidemic with potential life-long health implications. To date, relationships between the built environment and body mass index (BMI) have not been evaluated for youth, and have not been evaluated longitudinally.

Objectives: To determine if urban sprawl is associated with BMI for U.S. youth.

Methods: Using data from the 1997 National Longitudinal Survey of Youth (NLSY97), both cross-sectional and longitudinal analyses were conducted. Hierarchical modeling was used to relate characteristics of individuals, households, and places to BMI. Individual and household data were extracted from the NLSY97. The independent variable of interest was the county sprawl index, which was derived with principal components analyses from census and other data.

Results: In a cross-sectional analysis, the likelihood of U.S. adolescents (aged 12–17 years) being overweight or at risk of overweight (≥85th percentile relative to the Centers for Disease Control growth charts) was associated with county sprawl (p=0.022). In another cross-sectional analysis, after controlling for sociodemographic and behavioral covariates, the likelihood of young adults (aged 18–23 years) being obese was also associated with county sprawl (p=0.048). By contrast, in longitudinal analyses, BMI growth curves for individual youth over the 7 years of NLSY97, and BMI changes for individual youth who moved between counties, were not related to county sprawl (although coefficient signs were as expected).

Conclusions: Cross-sectional analyses suggest that urban form is associated with being overweight among U.S. youth. The strength of these relationships proved comparable to those previously reported for adults. Longitudinal analyses show no such relationship. It is unclear why these approaches give different results, but sample sizes, latent effects, and confounders may contribute.
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Introduction

In the United States, the prevalence of overweight and obesity has been steadily rising for all age, gender, race, and education subgroups.[1–9] Over the past 3 decades, obesity has more than doubled for preschool children aged 2–5 years and adolescents aged 12–19 years, and has more than tripled for children aged 6–11 years.[5]

As in adults, obesity in children causes hypertension, dyslipidemia, chronic inflammation, increased blood clotting, endothelial dysfunction, and hyperinsulinemia.[10] Children who are obese have greater prevalence of type 2 diabetes, sleep apnea with daytime somnolence that makes learning difficult, asthma, hypertension, orthopedic problems, and gall bladder disease.[11] About 41% of obese children and 80% of obese teens will become obese adults.[12]

To address the obesity epidemic and its health consequences, there is growing interest in built environments that encourage physical activity. The first studies reporting a direct relationship between the built environment and obesity were published in 2003.[13–16] After controlling for age, education, fruit and vegetable consumption, and other sociodemographic and behavioral covariates, Ewing et al.[13] found that adults living in sprawling counties had higher body mass indices (BMIs) and were more likely to be obese (BMI ≥30) than were their counterparts living in compact counties. Independent studies have since generally confirmed these original findings.[17–25] Specifically, all macrolevel (county or larger) studies, and all but one

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microlevel (neighborhood) studies, have found significant relationships, in the expected direction, between sprawl-like development patterns and BMI, after controlling for sociodemographic and other influences.

All of the above studies focused on adults and relied on cross-sectional data. Less is known about the built environment–obesity relationship for youth. There are many fewer studies, data are highly localized, and results are mixed. For low-income preschoolers in Cincinnati, overweight was not associated with proximity to playgrounds and fast food restaurants, nor was it associated with the level of neighborhood crime.[26] For San Diego adolescents, no significant relationship was found between BMI percentile and community design variables.[27] On the other hand, Australian youth were more likely to be overweight or obese where neighborhood traffic was perceived to be heavy or road safety was a concern to parents.[28]

Nearly all evidence of association between the physical environment and physical activity is based on cross-sectional data.[29] The documented relationship between walking and the built environment could as well be due to individuals who want to be physically active selecting walkable environments (self-selection), as due to walkable environments causing individuals to become more physically active than they would be otherwise (environmental determinism).[30]

In the planning literature, the possibility of self-selection has been addressed in various ways,[31–44] including the use of longitudinal data to study changes in travel behavior following moves between more- and less-accessible places.[45] Recently, Plantigna and Bernell[46] modeled residential choice and obesity jointly. Using the Ewing et al.[13] sprawl index, they confirmed the finding of direct association between sprawl and BMI in adults. However, they concluded that the direction of causality was the reverse of that posited in the original paper, specifically that individuals with higher BMIs were choosing to live in high-sprawl counties rather than high-sprawl counties raising the BMIs of average individuals.

The present study extends research on sprawl and obesity to American youth and conducts the first longitudinal analyses of the built environment and BMI change in an attempt to control for self-selection.

Methods

This research began in 2005 and continued into 2006, as a seventh year of longitudinal data became available from the National Longitudinal Survey of Youth 1997 (NLSY97). Initially, cross-sectional relationships were analyzed for a sample of American adolescents in a single year: 1997. The likelihood of being overweight or at risk of being overweight was related to the degree of sprawl in the adolescent's county of residence. Then, for the same cohort 5 years later, when all had grown up, the likelihood of being obese was related to the degree of sprawl in the young adult's county of residence.

Table 1. Sample sizes (n) by year for NLSY97 Rounds 1–6 (1997–2003)

Year	Sample size (n)
1997	8984
1998	8386
1999	8209
2000	8081
2001	7883
2002	7898
2003	7756

Two longitudinal analyses were conducted to follow up on positive findings in the cross-sectional analyses. In the first longitudinal analysis, BMI growth curves were related to the degree of sprawl for individual youth who remained in the same county for the entire series. Growth curves, characterized by intercepts and slopes, varied from individual to individual in predictable ways. In the second longitudinal analysis, BMI changes for individual youth moving between counties were related to differences in the degree of sprawl between new and old counties, again controlling for other influences.

The influence of self-selection was minimized in three ways: (1) **through the use of youth data**, assuming that the choice of residential location is the parents' and a youth's attitudes toward physical activity are not factored into the choice; (2) **through the use of built environmental data at the county level,** assuming that even if a household's choice of neighborhood is based on a desire for physical activity, the choice of county or region is based on other considerations such as job access and housing costs; and (3) **through the use of longitudinal data**, assuming that a youth's attitudes toward physical activity do not change overnight, and hence, any change in activity level following a move is due to the change in residential environment.

National Longitudinal Survey of Youth

Subjects in this study were youth surveyed as part of NLSY97. Although the focus of these surveys is on employment, extensive data are collected on other matters, including health, making this longitudinal survey suitable for the purposes of this study. For details on survey design, see the NLSY97 User's Guide.[47]

The original NLSY97 cohort consisted of 8984 American adolescents. Later rounds have followed these individuals into young adulthood, with some attrition along the way (Table 1). In the original cohort, the 8984 respondents came from 6811 unique households. One thousand eight hundred sixty-two households included more than one NLSY97 respondent.

Through a licensing system, NLSY97 geocode files were acquired by the authors. These files include the county of residence for each respondent in each survey year, which makes it possible to link individual records to place-level variables.

Only members of the NLSY97 cohort living in metropolitan areas were included in the analysis. Urban sprawl is a metropol-

Table 2. Variable definitions and sample statistics (in parentheses) for the initial cohort of 8984 respondents[a]

Individual variables		
BMI (each round)	Body mass index (continuous)	21.9 kg/m^2 (mean)
Age (each round)	Age in years as of interview date to nearest month (continuous)	14.9 years (mean)
Gender	Male (dichotomous)	51.2% (male)
Race/ethnicity	White non-Hispanic, black non-Hispanic, Hispanic, other race (categoric)	26.0% (black non-Hispanic) 21.2% (Hispanic) 3.5% (other race)
Smoker (each round)	Smoked one or more cigarettes per day in last 30 days (dichotomous)	9.0% (smoker)
Cigarettes (each round)	Number cigarettes smoked in last 30 days (continuous)	21.7 cigarettes (mean)
Work (each round)	Total hours worked at employee-type jobs during the year (continuous)	42.2 hours (mean)
Education (each round)	Highest grade completed (continuous)	7.7 years (mean)
TV watching (1997 and 2002)	Total hours watched per week (continuous—midpoint of ranges for 2002)	18.9 hours (mean)
Exercise (2002)	Days per week exercising for 30 minutes or more (continuous)	2.6 (mean for 2002 cohort)
Fruit and vegetable consumption (2002)	Times per week consuming fruits or vegetables (continuous—midpoint of ranges)	10.5 (mean for 2002 cohort)
Household variables		
Gross Household Income (1997)	Less than \$25,000, \$25,000–\$49,999, \$50,000–\$74,999, \$75,000 or more, income missing (categoric)	22.8% (\$25,000–\$49,999) 14.0% (\$50,000–\$74,999) 12.7% (\$75,000 or more) 30.4% (income missing)
Parents' highest grade (1997)	Less than high school, high school graduate, some college, college graduate (categoric)	31.5% (high school) 24.7% (some college) 24.1% (college)
Place variables		
County sprawl (2000)	Sprawl index for county of residence (continuous)	116.2 (mean)
Crime rate (2000)	FBI crime rate per 100,000 people (continuous)	4809 crimes (mean)
Heating degree days (1971–2000)	Average annual heating degree days, relative to a base temperature of 65°F	4088 degree days (mean)
Cooling degree days (1971–2000)	Average annual cooling degree days, relative to a base temperature of 65°F	1415 degree days (mean)

[a]For exact wording of NLSY97 questions, go to www.bls.gov/nls/quex/y97quexcbks.htm. Statistics apply to the combined sample of 8984 initial respondents: a cross-sectional sample representative of the U.S. population and a supplemental sample of black or Hispanic youths. Minorities were oversampled to permit analysis across race or ethnicity. Sample weights permit comparisons between the full NLSY97 sample and the national population in the same age range.

itan phenomenon, involving cities and their suburbs; low-density rural areas may produce very different relationships between the built environment, physical activity, and obesity.[48,49]

Individual- and Household-Level Variables

Body mass index (kg/m^2) was computed from self-reported height and weight. For adolescents, the Centers for Disease Control and Prevention (CDC)'s revised U.S. growth charts and software (available at www.cdc.gov/growthcharts) were used to determine BMI percentiles relative to age and gender reference groups. All adolescents at or above the 85th percentile were assigned to the overweight or at risk of overweight category.

Previous studies have shown that obesity prevalence depends on many sociodemographic and behavioral covariates.[1–9,50–55] Accordingly, the following individual variables were extracted from NLSY97: gender, race/ethnicity, age, cigarette use, hours worked, and highest grade completed by the youth respondent (Table 2). The reference groups for discrete variables were females, white non-Hispanics, and nonsmokers (less than one cigarette per day).

Household variables were extracted as well: household income and the highest grade attained by a household member (who was nearly always a parent) (Table 2). The reference groups were households with annual incomes of less than \$25,000 and households with highest grade attained of less than a high school degree; 2108 households either did not report income or reported unrealistically low incomes (<\$5000 per year). To keep from losing so many observations and still retain a variable viewed as critical to understanding youth obesity (household income), an income-missing category was created.

For youth, obesity prevalence is related to TV watching.[56,57] To control for this effect, and explore a possible causal pathway through which sprawl may affect weight, hours of TV watched each week were also extracted from NLSY97. In the first round (1997), NLSY97 asked only a subsample of respondents about hours of TV watched (primarily those aged 12–14 years). In the sixth round (2002), all respondents were asked about TV watching.

Two key determinants of BMI are exercise and diet. The first round of NLSY97 included questions on exercise ("In a typical week, how many days do you engage in exercise that lasts 30 minutes or more?") and diet ("In a typical week, how many days do you eat at least some green vegetables or fruit?). Unfortunately, these questions were asked only of respondents aged 13 years. In the sixth round, similar questions were asked of the entire remaining cohort (Table 2). Hence, exercise and diet could be included in the models, but only for a single round in a cross-sectional analysis.

Place-Level Variables

The same county sprawl index was used to model the built environment in this study as in the original study of adult obesity. It is a composite of six variables related to residential density and street accessibility, combined through principal components analysis.[13] The sprawl indices of Ewing et al.[13] have been validated in obesity and other research.[17,20,25,46,58–60]

The index was computed for additional counties or county equivalents to have sprawl data for more NLSY97 respondents. The 954 counties or county equivalents in the expanded sample represent the vast majority of counties lying within U.S. metropolitan areas, as defined by the U.S. Census Bureau in December 2003. (A total of 1135 counties and independent cities lie within metropolitan statistical areas, as such areas were defined in December 2003. By combining independent cities and counties whose land areas were merged in the Natural Resources Inventory [NRI], and dropping counties that did not meet density and area thresholds [tract areas <0.001 square miles and tract densities <100 persons/sq mi], this study ended up with sprawl measures for 954 counties and independent cities. Alaska counties, Puerto Rican municipios, the District of Columbia, and some independent cities in Virginia were excluded for lack of NRI data.) In 2000, almost 82% of the U.S. population lived in metropolitan counties for which county sprawl indices are now available.

The more compact the development in the county, the higher the value of the county sprawl index. Scores range from a high of 352 to a low of 55. At the most compact end of the scale are four New York City boroughs, San Francisco County, Philadelphia County, and Suffolk County (Boston). At the most sprawling end of the scale are outlying counties of metropolitan areas in the Southeast and Midwest United States. The county sprawl index is skewed. Few counties in the United States approach the densities of New York or San Francisco. (A list of counties and their sprawl scores is available on request from the corresponding author.)

A few built environment and health studies have included additional place-based variables representing safety or climate.[20,22,26,60] In a second-generation study of sprawl and obesity like this one, it was deemed necessary to control for both types of variables. Suburban counties have lower crime rates than urban counties, an effect potentially absorbed by the sprawl index in the absence of controls. Sprawling sunbelt counties have hotter climates than the rest of the country, another effect potentially soaked up by the sprawl index.

The Federal Bureau of Investigation crime rate per 100,000 population in 2000 was the chosen measure of crime. The rate includes both violent and property crimes.[61] Average annual heating-degree days and cooling-degree days for the period 1971 to 2000, relative to a base temperature of 65°F, were the chosen measures of climate. Heating- and cooling-degree days were averaged across weather stations in each county that has them (805 counties in this sample have from 1 to 20 stations). For counties without weather stations, values came from the closest county with stations.[62]

Hierarchical Modeling

Hierarchical (multilevel) models were estimated with HLM 6 (Hierarchical Linear and Nonlinear Modeling) software.[63] A hierarchical approach was required to account for dependence among observations, individuals, and households. This dependence violates the independence assumption of ordinary least squares (OLS) regression. Standard errors of OLS regression coefficients will be underestimated, and OLS coefficient and standard error estimates will be inefficient. Hierarchical modeling overcomes these limitations, accounting for the dependence among cases and producing more accurate estimates. Within a hierarchical model, each level in the data structure (e.g., repeated observations within individuals, individuals within households, and households within counties) is formally represented by its own submodel. The submodels are statistically linked.

In this study, hierarchical linear models were estimated for the continuous outcome (BMI), while hierarchical nonlinear models were estimated for dichotomous outcomes (being overweight or at risk of being overweight, or being obese). In some models, only the intercepts were allowed to randomly vary across higher level units, while all of the regression coefficients were treated as fixed. These are referred to as "random intercept" models. In other models, regression coefficients were allowed to randomly vary across higher level units as well, and interactions between individual, household, and place characteristics were captured. These are called random coefficient models.

First Cross-Sectional Analysis

The first cross-sectional analysis used Round-1 (1997) data because: (1) the sample was largest in the first round of NLSY97; (2) all subjects were adolescents; and (3) additional data were collected in a supplemental survey of parents, including their household incomes. The first round was the only round in which parents were interviewed. Excluding missing values and extreme outliers, BMI data were available for 8531 (95%) of the first-round respondents. (Respondents whose BMIs, based on reported weight and height, were <10 or >60 were dropped from the sample.) Of these, 6760 respondents (75% of the total cohort) lived in counties for which sprawl indices were available.

In this cross-sectional analysis, the odds of being overweight or at risk of overweight were regressed on individual characteristics in Level-1 models. The intercepts and coefficients of Level-1 models were regressed on household characteristics in Level-2 models. Initially, the intercepts and coefficients of Level-2 models were regressed on the county sprawl index, crime rate, and degree days in Level-3 models. When crime and climatic variables proved insignificant in all combinations and depleted the sample of counties, these were dropped from the Level-3 models.

All models included random effects. The sample was weighted using cross-sectional weights for Round 1. Cross-level interactions among individual, household, and place characteristics were seldom significant, and never sufficiently large to affect the relationship between county sprawl and a respondent's likelihood of being overweight or at risk of overweight. So the final cross-sectional models were of the random intercept form.

Second Cross-Sectional Analysis

The second cross-sectional analysis used Round-6 (2002) data because this was the first round to ask **all** respondents about physical activity, diet, and TV watching. BMI data were available for 7240 cohort members (81%) in the sixth round. (Respondents whose BMIs, based on reported weight and height, were <10 or >60 were dropped from the sample.) Of these, 5815 respondents (65% of the total cohort) lived in counties for which sprawl indices were available.

Whereas all youth respondents from the same households lived together in 1997, by 2002, respondents had grown up, and many were living in separate households. This required the use of a different hierarchical model structure than in the first cross-sectional analysis. Rather than individuals being treated as nested within households and households as nested within counties, individuals had to be independently identified with counties of residence. The best model structure that could be devised was two level, with the odds of being obese regressed on individual characteristics in Level-1 models, and intercepts and coefficients of Level-1 models regressed on county sprawl, crime, and climatic variables in Level-2 models. Again, crime and climatic variables proved insignificant in all combinations, and were dropped. All models included random effects. The sample was weighted using cross-sectional weights for the sixth round (2002).

The use of obesity as an outcome measure was prompted by the earlier study of sprawl and obesity in adults, where sprawl proved most strongly related to the dichotomous outcome, obese/nonobese.[13] All respondents had reached age 18 by 2002, and hence could be categorized by the adult standard of obesity (BMI ≥30). Age was included as a covariate to capture the natural increase in BMI with age.

First Longitudinal Analysis

The first longitudinal analysis used data for all NLSY97 rounds currently available, from 1997 through 2003. Growth curves were estimated for respondents who lived in the same county throughout the survey. BMI data were available for 6677 cohort members (74%) who participated in all seven rounds. (Respondents whose BMIs, based on reported weight and height, were <10 or >60 were dropped from the sample for the round in question.) Of these, 3667 (41% of the total cohort) remained in the same county for all rounds surveyed, and that county was one for which a sprawl index is available.

In the Level-1 models, BMIs of individual youth were modeled in terms of age, age-squared, cigarette use, and hours worked.[64] A quadratic specification was chosen based on plots of median BMI versus age. The intercepts and coefficients of Level-1 models were regressed on fixed individual and household characteristics in Level-2 models. The intercepts and coefficients of Level-2 models were regressed on county sprawl, crime, and climatic variables in Level-3 models. Crime and climatic variables were dropped when they proved insignificant. All models included random effects. The sample was weighted using panel weights for the entire seven rounds.

The use of BMI as an outcome measure was prompted by the mixed sample of adolescents and young adults in this longitudinal database. Overweight is assessed differently for children and adults; it is based on population characteristics for children (BMI percentiles relative to a reference population) and on health risks for adults (fixed BMI cut off points). CDC growth charts are available only up to age 240 months. For the most recent round (2003), less than 20% of the original NLSY97 cohort was still in this age range. Even for children, there may be some advantage in measuring changes in weight (as opposed to absolute weight levels) in terms of BMI rather than age-referenced BMI.[65]

Individual and household characteristics could not be represented in separate models because HLM 6.0 is limited to three levels, and place characteristics occupied Level 3. Given the restriction to three levels, the combination of individual and household characteristics in a single model was viewed as least damaging to the assumption of independence among observations (because most individuals in the data set came from different households).

Second Longitudinal Analysis

The models estimated in the second longitudinal analysis were repeated-measures models, because many individuals moved more than once.[63] The data were drawn from all consecutive rounds of NLSY97 from 1997 through 2003. BMI data were available for 3567 intercounty movers. (Respondents whose BMIs, based on reported weight and height, <10 or >60 in either round were dropped from the sample.) On average, about 8% of respondents moved between counties in any given round. The great majority (2427 or 68%) moved between metropolitan counties for which sprawl indices are available. Slightly more than half of these moved from less sprawling to more sprawling counties, while an almost equal number moved in the opposite direction.

In the second longitudinal analysis, Level-1 models related BMI of individual youth, after an intercounty move, to his/her BMI before the move plus various changes in status between rounds. In Level-2 models, the intercepts and coefficients of Level-1 models were regressed on individual characteristics that remained fixed over the course of the longitudinal survey, specifically gender and race/ethnicity. In Level-3 models, intercepts and coefficients of Level-2 models were regressed on baseline (1997) household characteristics. All models included random effects. The sample was

Table 3. Cross-sectional relationship between adolescent overweight or risk of overweight, socioeconomic and behavioral characteristics, and county sprawl index, 1997

	Overweight/risk of overweight (base model)			Overweight/risk of overweight (with TV watching)		
	Coeff	*t*	*p*	Coeff	*t*	*p*
Age	–0.0427	–1.50	0.13	–0.0149	–0.32	0.75
Male	0.500	7.07	<0.001	0.482	5.34	<0.001
Black non-Hispanic	0.431	4.42	<0.001	0.452	3.52	0.001
Hispanic	0.137	0.69	0.49	0.341	1.51	0.13
Other race	0.194	1.27	0.21	0.342	1.72	0.09
Smoker	–0.0042	–0.03	0.97	0.258	1.29	0.20
Hours worked	0.00096	0.35	0.73	0.00060	1.26	0.21
Hours TV watching	—	—	—	0.0130	4.50	<0.001
Income \$25–\$50k	–0.125	–1.08	0.28	–0.080	–0.49	0.62
Income \$50–\$75k	–0.240	–1.37	0.17	–0.230	–1.05	0.30
Income ≥ \$75k	–0.431	–2.96	0.004	–0.422	–2.06	0.04
Income missing	–0.261	–2.54	0.011	–0.359	–2.45	0.015
High school grad	–0.0182	–0.16	0.88	–0.0120	-0.08	0.94
Some college	–0.136	–1.08	0.28	–0.0838	–0.56	0.57
College grad	–0.411	–3.77	<0.001	–0.325	–2.60	0.010
County sprawl index[a]	–0.0030	–2.30	0.022	–0.0045	–2.47	0.014

[a]Higher values of the index correspond to more compact development, lower values to more sprawling development.

weighted using custom weights for respondents in the sample of movers.

It is common to use "lagged endogenous" variables as predictors in economic and planning research. BMI before the move was included as a Level-1 predictor to capture a host of factors that determine a person's BMI at a given age—some known and measurable, but most unknown and immeasurable. Change in age of respondents between rounds was included because more time between interviews translates into more time for weight gains. The time between intervals of NLSY97 was surprisingly variable for an annual survey (from 1 to 27 months). Changes in hours worked and household size were included to control for other lifestyle changes that might have accompanied moves. The change in built environment was represented by the difference in the degree of sprawl between new and old counties of residence. For movers to more compact counties, the difference was positive; for movers to more sprawling counties, the difference was negative.

Results

First Cross-Sectional Analysis

In this cross-sectional analysis, the odds of being overweight or at risk of being overweight were higher for males than females, higher for blacks than whites, lower for adolescents with college-educated parents, lower for adolescents from high-income households (≥\$75,000 per year), and lower for adolescents from households with missing income data (Table 3). This last finding may be due to the concentration of nonrespondents at the tails of the income distribution.[66] Unit nonresponse (household refusal to participate in surveys) tends to be highest among low-income households. Item nonresponse (household refusal to answer specific income questions) may be highest among high-income households.

Controlling for individual and household characteristics, the county sprawl index was related to overweight or risk of overweight in the expected direction at a significant level (t=–2.30, p=0.022). Because higher values of the index correspond to more compact development, a negative coefficient was expected. The odds of being overweight or at risk of overweight in a more sprawling county, one standard deviation below the mean county index, were 1.16 times the odds in a more compact county, one standard deviation above the mean index (95% confidence interval=1.02–1.31). Comparing the extremes, an adolescent living in Jackson County KS, the most sprawling county, had 2.41 times the odds of being overweight or at risk of overweight compared to an otherwise comparable youth living in Manhattan (New York County), the most compact county.

In a second model estimation, TV watching was added as an individual covariate. TV watching had the expected relationship (+) to being overweight or at risk of overweight (t=4.50, p<0.001). Despite a smaller sample, county sprawl was more significant with the TV variable in the model (t=–2.47, p=0.014). Adolescents in compact areas watch slightly more TV than those in sprawling areas. It may be that they have more time for TV in compact areas because they spend less time in travel. The county sprawl index soaks up some of the effect of TV watching when the former alone is included as a covariate.

Crime and climatic variables were also tested. Coefficients and significance levels for various combinations of place-level variables are presented in Table 4. In combination with county sprawl and individual and household characteristics, these variables failed to explain any variance in overweight/risk of overweight,

Table 4. Cross-sectional relationship between adolescent overweight or risk of overweight, county sprawl index, and other place-level variables, 1997 (controlling for socioeconomic and behavioral characteristics)

	Overweight/risk of overweight (base model)			Overweight/risk of overweight (with crime rate)			Overweight/risk of overweight (with crime rate and heating degree days)			Overweight/risk of overweight (with crime rate and cooling degree days)		
	Coeff	***t***	***p***	**Coeff**	***t***	***p***	**Coeff**	***t***	***p***	**Coeff**	***t***	***p***
County sprawl index[a]	–0.00262	–1.97	0.049	–0.00295	–2.13	0.034	–0.00289	–2.10	0.037	–0.00278	–1.99	0.047
Crime rate	—	—	—	0.000018	0.89	0.38	0.000016	0.82	0.41	0.000013	0.61	0.54
Heating degree days	—	—	—	—	—	—	–0.000007	–0.29	0.77	—	—	—
Cooling degree days	—	—	—	—	—	—	—	—	—	0.000029	0.51	0.61

[a]Higher values of the index correspond to more compact development, lower values to more sprawling development.

and because they cut into sample size due to missing county data, they were dropped from the final model. Differences in coefficients and significance levels of the county sprawl index between Tables 3 and 4 are due to the use of different county samples and loss of degrees of freedom.

Second Cross-Sectional Analysis

In the second cross-sectional analysis, involving young adults, the odds of being obese increased with age, decreased with highest grade completed, was higher for blacks than whites, and higher for Hispanics than non-Hispanics (Table 5). When added to the model, the number of times respondents exercised per week proved highly significant with the expected sign (–). The number of hours of TV watching also proved highly significant with the expected sign (+). The number of times per week eating fruits or vegetables had the expected sign (–) but was not significant. Cigarette smoking likewise had the expected sign (–) but was not significant.

The association between the county sprawl index and obesity was statistically significant after controlling for exercise, diet, and TV watching. It was not significant without these variables. The difference is due to the fact that young adults living in compact counties tended to exercise a little less, and watch a little more TV, than those living in sprawling counties, effects soaked up by the sprawl index when these variables were omitted from the model. After accounting for all covariates, a young adult living in Jackson County KS, had 2.18 times the odds of being obese compared to an otherwise comparable youth living in Manhattan (New York County).

Again, crime and climatic variables were not significant in combination with county sprawl and individual characteristics.

Table 5. Cross-sectional relationship between young adult obesity, socioeconomic and behavioral characteristics, and county sprawl index, 2002

	Obesity (base model)			Obesity (with exercise, fruit/vegetable consumption, and TV watching)		
	Coeff	***t***	***p***	**Coeff**	***t***	***p***
Age	0.182	5.75	<0.001	0.165	5.20	<0.001
Male	0.0041	0.05	0.96	0.0406	0.50	0.62
Black non-Hispanic	0.527	5.18	<0.001	0.407	3.91	<0.001
Hispanic	0.419	3.94	<0.001	0.373	3.51	0.001
Other race	0.305	1.49	0.14	0.285	1.37	0.17
Cigarettes	–0.00014	–0.76	0.45	–0.00031	–1.61	0.11
Hours worked	0.000073	1.61	0.11	0.000090	1.98	0.047
Highest grade completed	–0.133	–4.85	<0.001	–0.104	–3.71	<0.001
Times exercise	—	—	—	–0.0577	–3.11	0.002
Times eat fruits or vegetables	—	—	—	–0.00590	–1.24	0.22
Hours TV watching	—	—	—	0.0213	5.44	<0.001
County sprawl index[a]	–0.0022	–1.57	0.12	–0.0026	–1.98	0.048

[a]Higher values of the index correspond to more compact development, lower values to more sprawling development.

First Longitudinal Analysis

In the first longitudinal analysis, BMI increased with age through adolescence and young adulthood, but at a declining rate of increase (Table 6). The coefficients of age and age-squared were positive and negative, respectively, and highly significant. As expected from much past research, BMI fell with increasing cigarette consumption.

As for other individual and household characteristics, this longitudinal analysis generally confirmed the results of earlier cross-sectional analyses. BMI at the mean age was higher for males than females, higher for blacks than whites, higher for Hispanics than non-Hispanics, lower for youth from higher-income households (≥\$50,000 per year), and lower for youth from households with missing income data.

Cross-level interactions were significant for two Level-2 variables. The regression coefficient of age was positively related to the male and Hispanic variables, meaning that during their adolescent years, males gained weight faster than females and Hispanics gained weight faster than non-Hispanics. Only significant interaction terms were retained in the final model.

There is one important way in which the results of the cross-sectional analyses were not confirmed. Controlling for other predictors, neither BMI at the mean age nor BMI growth with age was related to county sprawl, although both had the expected signs. The discrepancy in the results was not due to different outcome variables used in the longitudinal and cross-sectional analyses, because the outcome variable BMI was tested with the first cross-sectional database and was as strongly related to sprawl (after controlling for age and gender) as the outcome actually modeled, being overweight or at risk of overweight.

Table 6. Longitudinal relationship between BMI growth for individual youth, socioeconomic and behavioral characteristics, and county sprawl index, 1997–2003

	BMI		
	Coeff	t	p
Age			
Base	1.053	11.24	<0.001
Male	0.0429	2.24	0.025
Hispanic	0.0925	3.25	0.002
County sprawl index	–0.00014	–0.37	0.71
Age^2	–0.0144	–5.39	<0.001
Cigarettes	–0.0010	–6.99	<0.001
Hours worked	–0.00008	–2.67	0.008
Male	0.742	4.32	<0.001
Black non-Hispanic	1.130	4.23	<0.001
Hispanic	0.755	2.72	0.007
Other race	0.536	1.52	0.13
Income \$25–\$50k	–0.459	–1.59	0.11
Income \$50–\$75k	–0.749	–2.24	0.025
Income ≥\$75k	–0.845	–2.69	0.008
Income missing	–0.926	–3.64	0.001
High school grad	0.352	1.19	0.24
Some college	0.225	0.76	0.45
College grad	–0.377	–1.32	0.19
County sprawl index[a]	–0.00082	–0.28	0.78

[a]Higher values of the index correspond to more compact development, lower values to more sprawling development.

Table 7. Longitudinal relationship between BMI for movers before and after moves, change in sprawl index, other changes between rounds, and certain individual characteristics, 1997–2002

	BMI (after move)		
	Coeff	t	p
BMI (before move)	0.917	51.6	<0.001
Change age	0.638	3.03	0.003
Change cigarettes	–0.00023	–0.62	0.54
Change work hours	–0.00008	–1.00	0.32
Change in household size	0.0110	0.37	0.71
Male	0.164	1.55	0.12
Hispanic	0.224	1.58	0.11
Change in county sprawl index[a]	–0.00022	–0.16	0.88

[a]Higher values of the index correspond to more compact development, lower values to more sprawling development.
BMI, body mass index.

Second Longitudinal Analysis

In the second longitudinal analysis, a youth's BMI after a move was most strongly associated with his or her BMI before the move (Table 7). This was expected. BMI after a move was also significantly associated with changes in age between rounds (time between interviews). This was also expected, because longer periods between interviews left more time for weight gains. Change in number of cigarettes smoked had the expected sign (–), because smoking tends to depress weight, but its coefficient was not significant.

Fixed individual and household characteristics had the expected signs but proved to be marginal predictors of BMI, both directly and through interactions with Level-1 covariates. Thus, only two covariates weakly related to BMI were retained in the Level-2 submodel, those being the male and Hispanic variables. These two groups tend to gain weight faster than others. No covariate was retained in the Level-3 submodel, leaving only unique random effects for each household at Level 3.

Controlling for other predictors, the difference in degree of sprawl between counties had the expected sign in the Level-1 equation (–) but was not even close to statistically significant. Recall that a positive value of this variable corresponds to move to a more compact county. The lack of significance of this and other variables that proved significant in cross-sectional analyses may be due to the relatively small sample of movers, and also to the fact that year-to-year changes in BMI are small for individuals (SD=0.59), whereas differences in BMI are large across individuals at any given point in time (SD=4.36 in the first cross-sectional sample).

Discussion

The growing interest in policy and environmental effects on youth health is indicated by the new focus on these issues in scientific journals as well as new initiatives of governmental and nongovernmental organizations such as CDC (Kids Walk-to-School Campaign); National Institutes of Health (Ways to Enhance Children's Activity & Nutrition Campaign); and Robert Wood Johnson Foundation (Childhood Obesity Initiative). Although there is a consistent and voluminous literature showing a relationship between the built environment and physical activity, the role of the built environment in the obesity epidemic has only recently been studied. Further, the literature to date has focused on adult obesity and has been strictly cross sectional, with all the limitations that this implies.

In cross-sectional analyses, after controlling for sociodemographic and behavioral covariates, adolescents living in sprawling counties were more likely to be overweight or at risk of overweight than those living in compact counties. Likewise, young adults living in sprawling counties were more likely to be obese.

Accounting for TV watching and exercise, relationships between sprawl and overweight or obesity grew stronger. Young adults living in compact counties tend to exercise a little less, and watch a little more TV, than those living in sprawling counties. Presumably, the former compensate by being more active in their routine daily activities. Although not classified as formal "exercise," they may walk to lunch rather than drive, walk up stairs in a multistory environment, or take public transportation to work that requires a walk at one or both ends.

The relationship between sprawl and overweight for U.S. youth actually proved stronger than that between sprawl and obesity for adults in the original study by Ewing et al.[13] (as measured by model coefficients, and hence, odds ratios: the coefficient of sprawl was 0.0030 for adolescents, 0.0026 for young adults, and 0.0021 for older adults). Significance levels were lower in this study only because the sample of individuals, and hence the sample of counties represented within the sample, was smaller in this study than in the original study.

In contrast to the cross-sectional analyses, longitudinal analyses showed little or no association between sprawl and weight gain among youth. The most that can be said is that the county sprawl index had the expected sign (–) in both longitudinal analyses.

It is unclear why these approaches give such different results, but sample sizes, confounders, and latent effects may contribute. Cross-sectional analyses examine individuals who are already overweight/obese, whereas the focus in longitudinal analyses is on **changes** in overweight/obesity. Year-to-year changes in BMI are likely to be small, and it may take several years before environmental effects are fully felt.

This study was exploratory. The built environment was measured at the county level, which is a large area compared to the living environments of most youth.[67] The availability and quality of parks, bike trails, and other physical activity settings were not modeled.[68] Objective measures of physical activity and diet were not available.[69] Self-reported measures of obesity were used, which vary in validity across population subgroups.[70] Residential preferences were not modeled, which leaves in doubt the direction of any causal relationship between sprawl and obesity. Due to the small number of studies in the literature and inconsistent findings, it would be premature to conclude that urban sprawl either does or does not cause obesity in any population cohort.

In conclusion, this study raises important questions regarding the potential effects of the built environment on the risk of obesity in youth. Given the enormous public health and economic consequences of childhood obesity, there is a pressing need for follow-up research that overcomes the aforementioned limitations.

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References

1. Flegal KM, Carroll MD, Ogden CL, Johnson CL. Prevalence and trends in obesity among U.S. adults, 1999–2000. JAMA 2002;288:1723–7.
2. Galuska DA, Serdula M, Pamuk E, Siegel PZ, Byers T. Trends in overweight among U.S. adults from 1987 to 1993: a multistate telephone survey. Am J Public Health 1996;86:1729–35.
3. Kuczmarski RJ, Flegal KM, Campbell SM, Johnson CL. Increasing prevalence of overweight among U.S. adults. The National Health and Nutrition Examination Surveys, 1960 to 1991. JAMA 1994;272:205–11.
4. Mokdad AH, Serdula MK, Dietz WH, Bowman BA, Marks JS, Koplan JP. The spread of the obesity epidemic in the United States, 1991–1998. JAMA 1999;282:1519–22.
5. Institute of Medicine CoPoOiCaY. Preventing childhood obesity: health in the balance. Washington DC: National Academies Press; 2004.
6. Troiano RP, Flegal KM. Overweight children and adolescents: description, epidemiology, and demographics. Pediatrics 1998;101(3 Pt 2):497–504.
7. Strauss RS, Pollack HA. Epidemic increase in childhood overweight, 1986–1998. JAMA 2001;286:2845–8.
8. Ogden CL, Carroll, MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. JAMA 2006;295:1549–55.
9. Mei Z, Scanlon KS, Grummer-Strawn LM, Freedman DS, Yip R, Trowbridge FL. Increasing prevalence of overweight among U.S. low-income preschool children: the Centers for Disease Control and Prevention pediatric nutrition surveillance, 1983 to 1995. Pediatrics 1998;101:E12.
10. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. Lancet 2002;360:473–82.
11. Trent M. Adolescent obesity: identifying a new group of at-risk youth. Pediatr Ann 2002;31:559–64.

12. Himes JH, Dietz WH. Guidelines for overweight in adolescent preventive services: recommendations from an expert committee. The Expert Committee on Clinical Guidelines for Overweight in Adolescent Preventive Services. Am J Clin Nutr 1994;59:307–16.
13. Ewing R, Schmid T, Killingsworth R, Zlot A, Raudenbush S. Relationship between urban sprawl and physical activity, obesity, and morbidity. Am J Health Promot 2003;18:47–57.
14. Catlin TK, Simoes EJ, Brownson RC. Environmental and policy factors associated with overweight among adults in Missouri. Am J Health Promot 2003;17:249–58.
15. Saelens BE, Sallis JF, Black JB, Chen D. Neighborhood-based differences in physical activity: an environment scale evaluation. Am J Public Health 2003;93:1552–8.
16. Giles-Corti B, Macintyre S, Clarkson J, Pikora T, Donovan RJ. Environmental and lifestyle factors associated with overweight and obesity in Perth, Australia. Am J Health Promot 2003;18:93–102.
17. Kelly-Schwartz A, Stockard J, Doyle S, Schlossberg M. Is sprawl unhealthy? A multi-level analysis of the relationship of metropolitan sprawl to the health of individuals. J Plann Ed Res 2004;24:184–96.
18. Lopez R. Urban sprawl and risk for being overweight or obese. Am J Public Health 2004;94:1574–9.
19. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med 2004;27:87–96.
20. Doyle S, Kelly-Schwartz A, Schlossberg M, Stockard J. Active community environments and health: the relationship of walkable and safe communities to individual health. J Am Plann Assoc 2006;72:19–31.
21. Frank LD, Sallis JF, Conway TL, Chapman JE, Saelens BE, Bachman W. Many pathways from land use to health. J Am Plann Assoc 2006;72:75–87.
22. Boehmer T, Hoehner C, Deshpande A, Brennan Ramirez L, Brownson R. Perceived and observed neighborhood indicators of obesity among urban adults. Int J Obesity, in press.
23. Soot S, Dirks L, Metaxatos P, Mohammadian K, Yanos G, Zhou J. Are sprawl and obesity related? Evidence from the Chicago area. ehttp://www.utc.uic.edu/Publications/BMIReportColor1jan2006.pdf (accessed April 3, 2006).
24. Rutt CD, Coleman KJ. Examining the relationships among built environment, physical activity, and body mass index in El Paso, TX. Prev Med 2005;40:831–41.
25. Cho S, Chen Z, Yen ST, Eastwood DB. The effects of urban sprawl on body mass index: where people live does matter. Proceedings of the 52nd Annual ACCI Conference, March 15–18, Baltimore, MD; 2006.
26. Burdette HL, Whitaker RC. Neighborhood playgrounds, fast food restaurants, and crime: relationships to overweight in low-income preschool children. Prev Med 2004;38:57–63.
27. Norman GJ, Nutter SK, Ryan S, Sallis JF, Calfas KJ, Patrick K. Community design and access to recreational facilities as correlates of adolescent physical activity and body-mass index. J Phys Activity Health 2006;3:S118–28.
28. Timperio A, Salmon J, Telford A, Crawford D. Perceptions of local neighbourhood environments and their relationship to childhood overweight and obesity. Int J Obes (Lond) 2005;29:170–5.
29. Transportation Research Board-Institute of Medicine. Does the built environment influence physical activity? Examining the evidence. Washington DC: National Academy of Sciences; 2005.
30. Ewing R. Can the physical environment determine physical activity levels? Exerc Sport Sci Rev 2005;33:69–75.
31. Kitamura R, Mokhtarian PL, Laidet L. A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. Transportation 1997;24:125–58.
32. Khattak AJ, Rodriguez D. Travel behavior in neo-traditional neighborhood developments: a case study in USA. Transport Res Part A 2005;39:481–500.
33. Lund H. Testing the claims of new urbanism: local access, pedestrian travel, and neighboring behaviors. J Am Plann Assoc 2003;69:414–29.
34. Lund H, Willson R, Cervero R. A re-evaluation of travel behavior in California TODs. J Architect Plann Res, in press.
35. Bagley MN, Mokhtarian PL. The impact of residential neighborhood type on travel behavior: a structural equations modeling approach. Ann Regional Sci 2002;36:279–97.
36. Cervero R, Duncan M. Residential self selection and rail commuting: a nested logit analysis. Working paper, University of California Transportation Center; 2005. http://www.uctc.net/papers/604.pdf
37. Greenwald M, Boarnet MG. The built environment as a determinant of walking behavior: analyzing non-work pedestrian travel in Portland, Oregon. Transport Res Rec 2001;1780:33–42.
38. Boarnet MG, Crane R. Travel by design: the influence of urban form on travel. New York: Oxford University Press; 2001.
39. Boarnet MG, Sarmiento S. Can land-use policy really affect travel behaviour? A study of the link between non-work travel and land-use characteristics. Urban Stud 1998;35:1155–69.
40. Schwanen T, Mokhtarian P, What if you live in the wrong neighborhood? The impact of residential neighborhood type dissonance on distance traveled. Transport Res Part D 2005;10:127–51.
41. Handy S, Cao X, Mokhtarian PL. Self-selection in the relationship between the built environment and walking. J Am Plann Assoc 2006;72:55–74.
42. Handy S, Cao X, Mokhtarian PL. Self-selection in the relationship between the built environment and walking. J Am Plann Assoc 2006;72:55–74.
43. Næss P. Residential location affects travel behavior—but how and why? The case of Copenhagen metropolitan area. Prog Plann 2005;63:167–257.
44. Greenwald MJ. The road less traveled: new urbanist inducements to travel mode substitution for non-work trips. J Plann Educ Res 2003;23:39–57.
45. Krizek KJ. Residential relocation and changes in urban travel: does neighborhood-scale urban form matter? J Am Plann Assoc 2003;69:265–81.
46. Plantinga AJ, Bernell S. The association between urban sprawl and obesity: is it a two-way street? Available at http://www.hhs.oregonstate.edu/faculty-staff/getfilefromdb.php?type=vitae&id=267 (last accessed September 14, 2005).
47. U.S. Department of Labor. HLSY97 user's guide: a guide to the rounds 1–5 data, National Longitudinal Survey of Youth 1997, Bureau of Labor Statistics. Washington DC: U.S. Department of Labor; 2003.
48. Wilcox S, Castro C, King AC, Housemann R, Brownson RC. Determinants of leisure time physical activity in rural compared with urban older and ethnically diverse women in the United States. J Epidemiol Community Health 2000;54:667–72.
49. Parks SE, Housemann RA, Brownson RC. Differential correlates of physical activity in urban and rural adults of various socioeconomic backgrounds in the United States. J Epidemiol Community Health 2003;57:29–35.
50. Freedman DS, Khan LK, Serdula MK, Galuska DA, Dietz WH. Trends and correlates of class 3 obesity in the United States from 1990 through 2000. JAMA 2002;288:1758–61.
51. Wellman NS, Friedberg B. Causes and consequences of adult obesity: health, social and economic impacts in the United States. Asia Pac J Clin Nutr 2002;11(suppl 8):S705–9.
52. Reidpath DD, Burns C, Garrard J, Mahoney M, Townsend M. An ecological study of the relationship between social and environmental determinants of obesity. Health Place 2002;8:141–5.
53. Hedley AA, Ogden CL, Johnson CL, Carroll MD, Curtin LR, Flegal KM. Prevalence of overweight and obesity among U.S. children, adolescents, and adults, 1999–2002. JAMA 2004;291:2847–50.
54. Chou SY, Grossman M, Saffer H. An economic analysis of adult obesity: results from the Behavioral Risk Factor Surveillance System. J Health Econ 2004;23:565–87.
55. Klesges RC, Meyers AW, Klesges LM, La Vasque ME. Smoking, body weight, and their effects on smoking behavior: a comprehensive review of the literature. Psychol Bull 1989;106:204–30.
56. Robinson TN. Television viewing and childhood obesity. Pediatr Clin North Am 2001;48:1017–25.
57. Gortmaker SL, Must A, Sobol AM, Peterson K, Colditz GA, Dietz WH. Television viewing as a cause of increasing obesity among children in the United States, 1986–1990. Arch Pediatr Adolesc Med 1996;150:356–62.
58. Ewing R, Pendall R, Chen D. Measuring sprawl and its transportation impacts. Transport Res Rec 2003;1832:175–183.
59. Ewing R, Schieber R, Zegeer C. Urban sprawl as a risk factor in motor vehicle occupant and pedestrian fatalities. Am J Public Health 2003;93:1541–1545.
60. Sturm R, Cohen DA. Suburban sprawl and physical and mental health. Public Health 2004;118:488–96.
61. Federal Bureau of Investigation—United States Department of Justice. Uniform Crime Reporting Program Data [United States]: county-level detailed arrest and offense data, 2000. FBI crime rate. http://www.icpsr.umich.edu/cgi-bin/SDA/NACJD/hsda?nacjd+03451-0004
62. National Climatic Data Center—National Oceanic and Atmospheric Administration. Annual degree days to selected bases, 1971–2000. United States Climate Normals—1971–2000. Climatography of the United States No. 81. Supplement No. 2, Ashville NC: National Environmental Satellite, Data, and Information Service; 2002.

63. Raudenbush SW, Bryk AS. HLM 6: hierarchical linear and nonlinear modeling. Chicago IL: Scientific Software International; 2004. http://www.ssicentral.com/hlm/index.html.
64. Raudenbush SW, Byrk AS. Hierarchical linear models: applications and data analysis methods. 2nd ed. Thousand Oaks CA: Sage Publications; 2002.
65. Cole TJ, Faith MS, Pietrobelli A, Heo M. What is the best measure of adiposity change in growing children: BMI, BMI%, BMI z-score or BMI centile? Eur J Clin Nutr 2005;59:419–25.
66. Frick JR, Grabka MK. Missing income information in panel data: incidence, imputation and its impact on the income distribution. www.sidos.ch/method/RC28/abstracts/Markus%20Grabka.pdf (accessed April 3, 2006).
67. Moudon AV, Lee C, Cheadle AD, et al. Operational definitions of walkable neighborhood: theoretical and empirical insights. J Phys Activity Health 2006;3:S99–177.
68. Saelens BE, Frank LD, Auffrey C, et al. Measuring physical environments of parks and playgrounds: EAPRS instrument development and inter-rater reliability. J Phys Activity Health 2006;3:S190–207.
69. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. Am J Prev Med 2005;28(2 suppl 2):117–125.
70. Yun S, Zhu BP, Black W, Brownson RC. A comparison of national estimates of obesity prevalence from the behavioral risk factor surveillance system and the National Health and Nutrition Examination Survey. Int J Obes (Lond) 2006;30:164–70.