Original Article
PEDIATRIC OBESITY

Obesity

Disentangling Overlapping Influences of Neighborhoods and Schools on Adolescent Body Mass Index

Tracy K. Richmond[1], Erin C. Dunn[2,3,4], Carly E. Milliren[5], Clare Rosenfeld Evans[6], and S.V. Subramanian[6]

Objective: To compare the simultaneous influence of schools and neighborhoods on adolescent body mass index (BMI).

Methods: Analyzing data from a nationally representative sample of adolescents in grades 7 to 12 (n = 18,200), cross-classified multilevel modeling was used to examine the fixed and random effects of individuals, schools, and neighborhoods on adolescent BMI. Additionally, the ability of school and neighborhood demographics to explain racial/ethnic disparities in BMI was assessed.

Results: There were 18,200 students nested in 128 schools and 2,259 neighborhoods, with 2,757 unique combinations of schools and neighborhoods. In girls, schools ($v_{ojk} = 0.18$, CI: 0.06–0.33) contributed twice that of neighborhoods ($u_{ojk} = 0.08$, CI: 0.01–0.20) to the variance in BMI, while in males, schools ($u_{ojk} = 0.15$, CI: 0.05–0.30) and neighborhoods ($v_{ojk} = 0.16$, CI: 0.05–0.31) had similar contributions. The interaction of the neighborhood and school random effects contributed significantly to the variance of male and female BMI. Characteristics of neighborhoods and schools explained a large portion of the racial/ethnic disparity in female BMI.

Conclusions: In an analysis of a nationally representative sample including multiple racial and ethnic groups, the BMI variance of adolescent females was associated with schools more than neighborhoods. In males, there was no difference in school or neighborhood association with BMI.

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Introduction

Despite recent plateauing of rates (1), child and adolescent obesity remains a critical public health problem for the United States today (2). Certain racial/ethnic groups are disproportionately affected, with Black females and Hispanic males having the highest rates of overweight and obesity (2). A large proportion of children with overweight or obesity have worsening of their weight status through childhood (3), and the majority continue to have overweight/obesity into adulthood with high risk for comorbidities (4). Thus, the elevated rates of overweight/obesity in children from racial/ethnic minority backgrounds potentially deepen racial/ethnic health disparities seen in adulthood.

In looking for potentially effective prevention and treatment strategies for childhood obesity generally, and racial/ethnic disparities more specifically, many have turned to the environments in which children and adolescents live, play, and go to school (5). Focusing on environmental contexts is appealing as contexts such as schools and neighborhoods impact a large number of youth. Additionally, Black and Hispanic youth are more often living in neighborhoods and attending schools with fewer health promoting resources (6), potentially explaining disparities in weight-related outcomes. Multilevel studies have found that neighborhood environments have a significant influence on youth weight status and dietary and physical activity behaviors (7-13). Among other findings, higher education levels in the community and fewer neighborhood problems have been shown to protect against excessive weight gain in youth (6). Relative to neighborhoods, schools have received little attention as a potential contextual influence on weight-related outcomes in youth; school-focused studies of weight-related outcomes have typically been single-level analyses evaluating program or intervention effects (14-16).

[1] Department of Medicine, Division of Adolescent Medicine, Boston Children's Hospital, Boston, Massachusetts, USA. Correspondence: Tracy K. Richmond (tracy.k.richmond@gmail.com) [2] Psychiatric and Neurodevelopmental Genetics Unit, Center for Human Genetic Research, Massachusetts General Hospital, Boston, Massachusetts, USA [3] Department of Psychiatry, Harvard Medical School, Boston, Massachusetts, USA [4] Stanley Center for Psychiatric Research, The Broad Institute of Harvard and MIT, Cambridge, Massachusetts, USA [5] Department of Medicine, Clinical Research Center, Boston Children's Hospital, Boston, Massachusetts, USA [6] Department of Social and Behavioral Sciences, Harvard School of Public Health, Boston, Massachusetts, USA.

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The existing multilevel obesity-related studies, however, have found a significant contextual effect of schools on individual student weight status, specifically finding that students attending higher-income schools and schools with lower proportions of racial/ethnic minority students had lower average body mass index (BMI) (3,5).

Existing contextual studies have largely ignored the fact that children and adolescents are exposed to multiple influential environments throughout their day, e.g., by attending schools outside of their home neighborhood. As school choice has become the norm, a large portion of youth are attending schools outside of their neighborhood, potentially experiencing different environmental influences at home versus school. In order to most effectively allocate and target limited public health resources, it is important to understand how these potentially different environments compare in their influence on youth BMI. To our knowledge, no study has yet simultaneously examined school and neighborhood contextual influences on youth BMI in a U.S.-based cohort. Studies examining potential contextual explanations for racial/ethnic disparities are similarly lacking. Thus, our study had three objectives: (1) to determine the relative contribution to youth BMI of the neighborhood of residence and school attended (i.e., random effects' variance contributions); (2) to examine the association between neighborhood and school demographic characteristics and adolescent BMI (i.e., fixed effects); and (3) to determine to what degree neighborhood and school characteristics explain individual racial/ethnic disparities in BMI.

Methods

Study sample

This study uses data from Wave I of the National Longitudinal Study of Adolescent to Adult Health (Add Health), a nationally representative longitudinal study of adolescents with baseline (Wave I) data collected in 1994 to 1995 when participants were aged 12 to 19 years. Though baseline data are now more than 20 years old, Add Health remains unique in its multilevel data structure including information on individuals, schools, and neighborhoods. Add Health used schools as its primary sampling unit (17). All students within a sampled school were asked to participate in an in-school survey and were then eligible for a more comprehensive in-home survey. Eligible students were stratified by gender and grade and then randomly selected for the Wave I in-home survey. This resulted in a final in-home sample of 20,745 students from which our analytic sample is derived.

From the initial sample of 20,745, individuals missing data on any of the key variables were excluded from the analysis. We excluded those missing: school information or who were from the non-nationally representative sample (i.e., attended schools sampled for genetic analysis) (n = 660); outcome data (i.e., height or weight information, n = 548); data for our individual predictors (n = 822); school-level or (n = 508) neighborhood-level demographics (n = 7). Our final analytic sample consisted of 18,200 students. There are small but statistically significant differences in age, gender, and race between the excluded and analytic sample. Those excluded were slightly older (16.0 years among excluded compared with 15.6 years among included; $P < 0.001$), more likely to be female (57% compared with 50%; $P < 0.001$), less likely to be White (46% compared with 51%), and more likely to be Hispanic (20% compared with 15%; $P < 0.001$ for race).

The use of the de-identified Add Health data for this analysis was approved by the Boston Children's Hospital IRB.

Study variables

Outcome variable. BMI (kg/m^2) calculated from self-reported weight (kg) and height (m).

Race/ethnicity. The individual-level race/ethnicity independent variable was constructed to mirror current U.S. Census definitions of race/ethnicity (18). Participants who indicated they were of Hispanic ethnicity were considered Hispanic regardless of which race category(ies) they chose. Next, all participants were asked to indicate their race: White; Black or African American; American Indian or Native American; Asian or Pacific Islander; and other. Those choosing more than one racial category were considered multiracial. A school-level measure of racial composition (percent of the student body that is White) was constructed from responses to the in-school survey. The neighborhood-level racial/ethnic composition was based on the census variable describing the percentage at the tract level who were White.

Socioeconomic markers. We included markers of socioeconomic position—household income and educational attainment—at the individual, school, and neighborhood levels.

Education. Parent respondents (usually the mother or female guardian) reported their highest grade completed in school as well as that of their spouse/partner. We dichotomized responses into having a college degree or not (0 = no college degree; 1 = college degree or beyond) using the higher achievement of the two parents/guardians. We aggregated the individual-level responses to create a school-level variable indicating the highest education level attained by parents of the student body (the percent of parents with at least a college education). For the neighborhood variable, we used the census variable that reports the percentage of the population in the census tract with at least a college education.

Household income. At the individual level, we used the parental response to the question asking whether or not parents were currently receiving public assistance (yes/no) as a proxy marker for household income level. We chose this independent variable as it was the only marker of income that was available for neighborhoods and individuals and thus able to be aggregated to schools. We wanted parallel measures in order to have cleaner comparisons of fixed effects from one level to the next. When parental response was missing, we used the adolescent's response to whether his/her mother was receiving public assistance. We aggregated the individual-level responses to create a school-level percent of the student-body receiving public assistance. For the neighborhood variable, we used the census measure that reports the percentage of the population in the census tract receiving public assistance.

Additional covariates. We adjusted for the participants' age (years).

Analyses

We first examined univariate distributions and performed bivariate analyses between our variables of interest. Because of the known sex differences for weight-related outcomes (2,5) as well as significant interactions between sex and age, race/ethnicity, and household income as well as household education, we sex-stratified all models.

We constructed a series of cross-classified multilevel models (CCMM) each with BMI as the outcome. In addition to the random

TABLE 1 Descriptive statistics on individuals in the National Longitudinal Study of Adolescent to Adult Health (Add Health) (*N* = 18,200)

	n (%) or mean (SD)			
	Total sample (*N* = 18,200)	Males (*n* = 9,147)	Females (*n* = 9,053)	*P*
Participant characteristics				
Age (years)	15.6 (1.7)	15.7 (1.7)	15.5 (1.7)	<0.0001
Race				0.0211
White	9,252 (51%)	4,682 (51%)	4,570 (49%)	
Black/African American	3,741 (21%)	1,806 (48%)	1,935 (52%)	
Asian	1,172 (6%)	622 (53%)	550 (47%)	
Hispanic	2,789 (15%)	1,423 (51%)	1,366 (49%)	
Native American	100 (1%)	57 (57%)	43 (43%)	
Other	160 (1%)	84 (53%)	76 (48%)	
Multiracial	986 (5%)	473 (48%)	513 (52%)	
Parent graduated college				0.6111
No college degree	12,388 (68%)	6,210 (50%)	6,178 (50%)	
College degree or higher	5,812 (32%)	2,937 (51%)	2,875 (49%)	
Parent on public assistance				0.0197
Not on public assistance	16,487 (91%)	8,332 (51%)	8,155 (49%)	
On public assistance	1,713 (9%)	815 (48%)	898 (52%)	
BMI	22.6 (4.5)	22.8 (4.5)	22.3 (4.5)	<0.0001
School and neighborhood characteristics	**Mean (SD)**	**Median**	**Minimum**	**Maximum**
School (*n* = 128)				
% White	47.5 (25.5)	55.0	0	85.9
% with college degree	31.7 (16.9)	28.3	5.5	91.2
% on public assistance	10.4 (9.4)	7.2	0	45.4
Neighborhood (*n* = 2,259)				
% White	66.5 (32.9)	79.6	0	100
% with college degree	23.6 (14.6)	20.2	0	82.5
% on public assistance	10.7 (9.9)	7.3	0	67.5

effects of schools and neighborhoods, we also accounted for the possible interaction of the random effects of schools and neighborhoods (19). Our models included: (1) model 1, a null model with the random effects of both school and neighborhood as well as the interaction of school and neighborhood included, but no additional covariates; (2) model 2 created by adding individual-level covariates to model 1; (3) model 3 created by adding school-level covariates to model 2; (4) model 4 created by adding neighborhood-level covariates to model 2; and (5) model 5, a fully adjusted model with individual-, school-, and neighborhood-level covariates also accounting for the random effects of individuals, schools, neighborhoods, and the interaction of schools and neighborhoods.

We compared the random effects' variance components in model 2 (i.e., after individual characteristics are accounted for but before further explanatory variables are added) to address objective 1. We examined the fixed effects of individual, school, and neighborhood characteristics in our final model (model 5) to address objective 2. Finally, to address objective 3, we examined the effect size of individual race/ethnicity across models 2 to 5 to determine if school and neighborhood characteristics helped explain racial/ethnic differences in BMI.

All univariate and bivariate analyses were performed using SAS version 9.3. The CCMMs were implemented using MLwiN version 2.26. The software utilizes Bayesian estimation procedures using Markov Chain Monte Carlo methods with a Metropolis-Hastings sampling algorithm allowing for simultaneous modeling of nonhierarchically nested contexts. The Markov Chain Monte Carlo estimation was performed with 500 burn-in replication, 5,000 updates, and a monitoring chain length of 5,000. Noninformative priors were used from a four-level model (the interaction of school and neighborhood, neighborhood, school, individual) assuming a hierarchical nesting structure. All statistical tests were performed at a two-sided α-level of 0.05 with the exception of the random effects for which one-tailed tests were performed (as by definition these cannot be less than zero).

Results

Adolescents attended 128 schools and lived in 2,259 different neighborhoods resulting in 2,757 unique combinations of schools and neighborhoods. Approximately 21% of students attended schools whose sociodemographic characteristics differed from that of their

TABLE 2 Nested models within female participants in the National Longitudinal Study of Adolescent Health ($N = 9,053$) describing association between individual, school, and neighborhood predictors and current BMI

	Model 1	Model 2	Model 3	Model 4	Model 5
	Null, cross-classified	Individual covariates, cross-classified	Individual and school covariates, cross-classified	Individual and neighborhood covariates, cross-classified	Individual, school, and neighborhood covariates, cross-classified
Fixed effect estimates (confidence intervals)					
Intercept (SE)	22.18 (0.11)	16.58 (0.46)	16.72 (0.54)	17.5 (0.55)	17.36 (0.59)
Individual level					
Age	-	0.35 (0.30 to 0.41)[b]	0.37 (0.31 to 0.42)[b]	0.35 (0.30 to 0.41)[b]	0.36 (0.31 to 0.42)[b]
Public assistance	-	0.60 (0.29 to 0.90)[b]	0.46 (0.14 to 0.79)[b]	0.51 (0.19 to 0.83)[b]	0.43 (0.11 to 0.74)[b]
College degree (parent)	-	−0.68 (−0.89 to −0.48)[b]	−0.58 (−0.78 to −0.37)[b]	−0.55 (−0.75 to −0.34)[b]	−0.51 (−0.72 to −0.30)[b]
Race					
White	-	Ref.	Ref.	Ref.	Ref.
Black	-	1.40 (1.14 to 1.67)[b]	1.26 (0.97 to 1.56)[b]	1.07 (0.75 to 1.39)[b]	1.02 (0.70 to 1.35)[b]
Asian	-	−1.03 (−1.46 to −0.60)[b]	−1.1 (−1.55 to −0.66)[b]	−1.12 (−1.55 to −0.69)[b]	−1.14 (−1.59 to −0.71)[b]
Hispanic	-	0.66 (0.35 to 0.96)[b]	0.47 (0.13 to 0.79)[b]	0.52 (0.21 to 0.83)[b]	0.43 (0.10 to 0.76)[b]
Native American	-	1.31 (−0.05 to 2.63)	1.12 (−0.22 to 2.46)	1.20 (−0.14 to 2.54)	1.05 (−0.25 to 2.34)
Other	-	−0.83 (−1.83 to 0.13)	−0.96 (−1.96 to 0.05)	−0.90 (−1.89 to 0.10)	−0.97 (−1.96 to 0.01)
Multiracial	-	0.79 (0.39 to 1.18)[b]	0.70 (0.30 to 1.11)[b]	0.69 (0.28 to 1.09)[b]	0.65 (0.23 to 1.06)[b]
School level					
% White	-	-	−0.002 (−0.01 to 0.004)	-	0.001 (−0.01 to 0.01)
% College degree	-	-	−0.01 (−0.02 to −0.003)[b]	-	−0.005 (−0.02 to 0.01)
% Public assistance	-	-	0.02 (0.003 to 0.04)[b]	-	0.02 (0.001 to 0.04)[b]
Neighborhood level					
% White	-	-	-	−0.01 (−0.01 to −0.0003)[b]	−0.01 (−0.01 to −0.0004)[b]
% College degree	-	-	-	−0.02 (−0.03 to −0.01)[b]	−0.02 (−0.03 to −0.01)[b]
% Public assistance	-	-	-	0.01 (−0.01 to 0.03)	−0.002 (−0.02 to 0.02)
Random effects' variance, components (U1-U4[a]) (credible intervals)					
U4 school[b] neighborhood (CI)	0.41 (0.17 to 0.73)[b]	0.28 (0.12 to 0.50)[b]	0.23 (0.1 to 0.46)[b]	0.21 (0.09 to 0.42)[b]	0.19 (0.06 to 0.40)[b]
U3 neighborhood (CI)	0.07 (0.01 to 0.18)[b]	0.08 (0.01 to 0.20)[b]	0.01 (0.002 to 0.03)[b]	0.01 (0.002 to 0.03)[b]	0.10 (0.02 to 0.31)[b]
U2 school (CI)	0.91 (0.61 to 1.30)[b]	0.18 (0.06 to 0.33)[b]	0.09 (0.02 to 0.21)[b]	0.10 (0.03 to 0.22)[b]	0.05 (0.001 to 0.15)[b]
U1 individual (CI)	18.67 (18.10 to 19.26)[b]	18.22 (17.68 to 18.80)[b]	18.29 (17.75 to 18.84)[b]	18.28 (17.74 to 18.83)[b]	18.24 (17.71 to 18.81)[b]

[a]U1-U4 are the random effects' variance components (σ^2) of the different levels: U1 = individual-level variance component; U2 = school-level variance component; U3 = neighborhood-level variance component; U4 = the interaction of the school and neighborhood variance components.
[b]Significance at the $P < 0.05$ level.

TABLE 3 Nested models within male participants in the National Longitudinal Study of Adolescent Health (N = 9,147) describing association between individual, school, and neighborhood predictors and current BMI

	Model 1	Model 2	Model 3	Model 4	Model 5
	Null, cross-classified	Individual covariates, cross-classified	Individual and school covariates, cross-classified	Individual and neighborhood covariates, cross-classified	Individual, school, and neighborhood covariates, cross-classified
Fixed effect estimates (confidence intervals)					
Intercept (SE)	22.45 (0.1)	14.77 (0.47)	14.89 (0.56)	14.99 (0.57)	15.02 (0.62)
Individual level					
Age	-	0.50 (0.45 to 0.56)[b]	0.51 (0.45 to 0.57)[b]	0.51 (0.45 to 0.56)[b]	0.51 (0.45 to 0.57)[b]
Public assistance	-	−0.07 (−0.41 to 0.25)	−0.15 (−0.48 to 0.18)	−0.17 (−0.50 to 0.16)	−0.20 (−0.53 to 0.13)
College degree (parent)	-	−0.41 (−0.61 to −0.21)[b]	−0.31 (−0.52 to −0.11)[b]	−0.30 (−0.50 to −0.09)[b]	−0.27 (−0.47 to −0.06)[b]
Race					
White	-	Ref.	Ref.	Ref.	Ref.
Black	-	0.23 (−0.04 to 0.50)	0.20 (−0.10 to 0.50)	0.08 (−0.25 to 0.40)	0.08 (−0.26 to 0.41)
Asian	-	−0.27 (−0.68 to 0.13)	−0.23 (−0.65 to 0.20)	−0.27 (−0.69 to 0.15)	−0.24 (−0.67 to 0.19)
Hispanic	-	0.49 (0.19 to 0.78)[b]	0.46 (0.12 to 0.77)[b]	0.45 (0.14 to 0.74)[b]	0.44 (0.10 to 0.76)[b]
Native American	-	2.97 (1.78 to 4.17)[b]	2.80 (1.61 to 3.99)[b]	2.83 (1.63 to 4.03)[b]	2.74 (1.55 to 3.94)[b]
Other	-	−0.37 (−1.33 to 0.59)	−0.34 (−1.30 to 0.60)	−0.39 (−1.35 to 0.55)	−0.38 (−1.37 to 0.59)
Multiracial	-	0.11 (−0.31 to 0.53)	0.12 (−0.31 to 0.54)	0.10 (−0.32 to 0.51)	0.10 (−0.32 to 0.54)
School level					
% White	-	-	0.001 (−0.005 to 0.01)	-	0.002 (−0.01 to 0.01)
% College degree	-	-	−0.01 (−0.021 to −0.003)[b]	-	−0.01 (−0.02 to 0.004)
% Public assistance	-	-	0.01 (−0.01 to 0.03)	-	0.01 (−0.01 to 0.03)
Neighborhood level					
% White	-	-	-	0.0001 (−0.01 to 0.01)	−0.001 (−0.01 to 0.01)
% College degree	-	-	-	−0.02 (−0.03 to −0.01)[b]	−0.01 (−0.02 to −0.0003)[b]
% Public assistance	-	-	-	0.02 (−0.003 to 0.04)	0.01 (−0.01 to 0.03)
Random effects' variance components U1-U4[a] (credible intervals)					
U4 school[b]neighborhood	0.10 (0.02 to 0.26)[b]	0.02 (0.002 to 0.14)[b]	0.07 (0.01 to 0.23)[b]	0.07 (0.01 to 0.21)[b]	0.09 (0.03 to 0.21)[b]
U3 neighborhood	0.10 (0.03 to 0.27)[b]	0.16 (0.05 to 0.31)[b]	0.09 (0.004 to 0.25)[b]	0.08 (0.003 to 0.22)[b]	0.07 (0.02 to 0.16)[b]
U2 school	0.83 (0.55 to 1.18)[b]	0.15 (0.05 to 0.30)[b]	0.13 (0.04 to 0.25)[b]	0.11 (0.04 to 0.22)[b]	0.11 (0.04 to 0.24)[b]
U1 individual	19.13 (18.56 to 19.7)[b]	18.74 (18.2 to 19.32)[b]	18.73 (18.18 to 19.27)[b]	18.74 (18.19 to 19.28)[b]	18.72 (18.18 to 19.28)[b]

[a]U1-U4 are the random effects' variance components (σ^2) of the different levels: U1 = individual-level variance component; U2 = school-level variance component; U3 = neighborhood-level variance component; U4 = the interaction of the school and neighborhood variance components.
[b]Significance at the $P < 0.05$ level.

neighborhood (i.e., those who attended a low-minority school but lived in a high-minority neighborhood or vice versa, $P < 0.001$, McNemar's).

Results of univariate analyses

The mean age of the sample was 15.6 (SD = 1.7) years. The mean self-reported BMI was 22.6 kg/m^2. A total of 9.4% of youth participants had mothers receiving public assistance and 31.9% had at least one parent with a college degree.

At the school level, the mean percentage of students with parents who had at least a college degree was 31.7% and receiving public assistance was 10.4%. At the neighborhood level, the mean percent of the tract with a college degree was 23.6% and receiving public assistance was 10.7%.

Results of bivariate analyses

Table 1 shows demographic and anthropometric characteristics by gender. There were very small but statistically significant gender differences in age, percent receiving public assistance, race/ethnicity, and measured BMI.

Results of cross-classified multilevel analyses

Tables 2 and 3 present the results of our CCMM building from our null model (model 1) to a fully adjusted cross-classified model (model 5) for females and males, respectively. The interaction term of school and neighborhood variance components was significant in null models so included in all subsequent models.

Females. We first examined the variance contribution of neighborhoods and schools as well as their interaction across our models to address objective 1 with a specific focus on model 2. In our null model, we found that the variance contribution of schools to BMI ($u_{ojk} = 0.91$, CI: 0.61–1.30) was more than 10 times that of neighborhoods ($v_{ojk} = 0.07$, CI: 0.01–0.18) while the interaction term of neighborhoods and schools was also large and significant ($u_{ojk} \times v_{ojk} = 0.41$, CI: 0.17–0.73). However, model 2 demonstrated that there were large effects attributable to the demographics of kids clustering in schools and neighborhoods, especially in schools; after adjusting for the demographic characteristics of schools and neighborhoods, we found that the contribution of schools was greatly reduced ($v_{ojk} = 0.18$, CI: 0.06–0.33) but still was more than twice that of neighborhoods ($u_{ojk} = 0.08$, CI: 0.01–0.20). The interaction term of the random effects of schools and neighborhoods was larger than each individually ($u_{ojk} \times v_{ojk} = 0.28$, CI: 0.12–0.50) indicating that the effect of schools was moderated by its neighborhood pair and vice versa.

In addressing objective 2, we examined the fixed effect of the demographic features of both schools and neighborhoods and found significant but universally small effects for both.

To address objective 3, we examined the magnitude of the effects of the various racial/ethnic groups on BMI relative to Whites in models without (model 2) and with (model 5) adjustment for school and neighborhood demographics. In model 2, we noted that Black and Hispanic females had on average higher BMIs than White females. However, when we adjusted for school and neighborhood demographics in model 5, this disparity in BMI was reduced by 20% to 40% across the various racial/ethnic groups. When we compared the β coefficients in models 3 and 4, we found that neighborhood demographics explained more of the disparity between Black and White female BMI while school demographics explained more of the disparity between Hispanic and White female BMI.

Males. To address objective 1 in males, we compared the variance components of neighborhoods, schools, and their interaction across models. In our null model, both schools ($u_{ojk} = 0.83$, CI: 0.55–1.18) and neighborhoods ($v_{ojk} = 0.10$, CI: 0.03–0.27) contributed to adolescent BMI, though the schools' effect was more than eight times that of neighborhoods. The interaction of the variance components was also significant and similar to that of neighborhoods ($u_{ojk} \times v_{ojk} = 0.10$, CI: 0.02–0.26). With the addition of individual demographics (model 2), the school variance contribution was markedly reduced (from $u_{ojk} = 0.8$ to $u_{ojk} = 0.15$) to a value similar to that of neighborhoods ($v_{oj} = 0.16$). The value of the interaction term was much less than either that of schools or neighborhoods ($u_{ojk} \times v_{ojk} = 0.02$, CI: 0.002–0.14). The addition of school and neighborhood factors reduced but did not fully explain the variance in schools or neighborhoods.

In examining the fixed effects of the sociodemographic features of schools and neighborhoods to address objective 2, we found only the neighborhood education level was significantly associated with individual BMI though the effect size was small ($b_{ojj} = -0.01$, CI: -0.02 to -0.001).

In addressing objective 3 in males, we compared the effect sizes of the various racial/ethnic groups on BMI relative to Whites across models 2 through 5. In model 2 we noted that Hispanic and Native American males had on average higher BMIs than White males. In contrast to females, the magnitude of these effects was remarkably stable even with the addition of school and neighborhood demographics.

Discussion

In one of the only large nationally representative multilevel cohorts of adolescents, we found important sex-based differences in the influence of schools and neighborhoods on individual BMI. In females, schools contributed twice as much as neighborhoods to the variance in BMI; surprisingly, it was the combination of schools and neighborhoods that contributed the most to female BMI. Males had very different findings with school and neighborhoods contributing roughly equally to the variance in weight status and with the effect size of the contribution of the school and neighborhood interactions much lower than either schools or neighborhoods alone. Importantly, we also found that school and neighborhood demographics explained a large portion of the racial/ethnic disparities in weight status between White, Black, Native American, and Hispanic females.

Our study contributes to the very sparse literature examining multiple contextual contributors to child and adolescent weight-related outcomes and adds to this literature by recognizing that the interaction of school and neighborhood environments hold specific importance. In our study, females had greater influence from their schools while males had roughly equal influence from their schools and neighborhoods. Our findings for females are in concert with studies from New Zealand and England demonstrating a larger influence of schools on weight-related outcomes when compared with neighborhoods (20,21). Our study differs from these studies in our sex-stratified approach which allows us to discern differences by sex. Future studies are needed to understand U.S.-based sex differences in contextual influences on weight-related outcomes as well as to understand potential different geographic differences.

Our findings of the relative importance of school and neighborhood features also differ from previous studies using Add Health data. For example, our prior work examining the school contextual effect on student body mass index (BMI) (without considering neighborhood effects) found significant and moderate inverse effects of the school median household income on both male ($\beta = -0.29$) and female ($\beta = -0.37$) BMI (3). Much larger school-level random effects were also detected in previous work compared with the current work, in both girls ($u_{oj} = 0.46$, ICC = 0.011 in a fully adjusted model with school only *v.* $u_{ojk} = 0.05$, ICC = 0.003 in our current models accounting for school and neighborhood) and boys ($u_{oj} = 0.38$, ICC = 0.0078 in our models accounting for schools only *v.* $u_{ojk} = 0.11$, ICC = 0.006 accounting for both school and neighborhood). In comparing these two sets of findings, it is clear that not accounting for the multiple contexts that influence individual's health may risk misattributing variance to the context being studied.

This is the first health-related study of which we are aware that includes the interaction term of the cross-classified environments. We find large and significant effects of the interaction of schools and neighborhoods, particularly in females. This indicates that the effect of schools is patterned by the neighborhood in which the student resides while the effect of neighborhoods is impacted by the school the student attends. Given the rise in school choice, the number and types of school-neighborhood combinations are increasing. In Add Health, a large percentage of students attend non-neighborhoods schools. Future studies are needed not just to understand the impact of schools and neighborhoods but also how they might operate synergistically or in opposition.

As in other studies, we find that accounting for the characteristics of one's neighborhood and school can largely explain the racial/ethnic disparities commonly seen between Hispanic and Black females when compared with White females (22). The influence of school and neighborhood demographics is not surprising given the number of hours girls (and boys) spend in school each year being exposed to dietary and physical activity opportunities and influences (e.g., school lunch, type, and frequency of physical education) coupled with all of the dietary and physical activity influences in one's neighborhood (e.g., fast food restaurants, neighborhood safety). Surprisingly, in males, the disparity in BMI between Hispanic and White males persisted even after accounting for key school and neighborhood characteristics. Future research is needed to better understand the different contributors to racial/ethnic disparities by gender and thus the most effective targets for reducing these disparities.

There are limitations to this study that need to be acknowledged. This study relies on self-report of height and weight in calculating adolescent BMI as Add Health did not begin collecting objective height and weight measurements until Wave II. However, the use of self-reported BMI in this study is justified, as studies comparing self-report and measured height and weight in Add Health found very little miscategorization of weight (23). A second limitation to this study is our inability to incorporate sampling weights as the algorithms to include them are not yet worked out for CCMM. Thus, the results should be viewed with caution when considering generalizing to the U.S. population of youth. Additionally, we are unable to determine the mechanisms through which schools and neighborhoods are exerting their influence on youth. Finally, these data are now more than 20 years old. However, Add Health is the only high-quality, multilevel, nationally representative cohort with information on health-related outcomes as well as schools and neighborhoods of which we are aware. We believe the strengths outweigh the limitations as this is the first article of which we are aware to simultaneously examine the influence of schools, neighborhoods, and their interactions on youth weight status.

Conclusion

In conclusion, we find that both schools and neighborhoods are influential to youth weight status though the importance of each context differs by sex. We believe that understanding the relative importance of these two contexts is paramount to effectively and efficiently targeting obesity prevention and intervention efforts. Future research is needed to understand through what mechanisms these contexts are exerting their influence in an effort to further explicate the sex and racial/ethnic differences found here. O

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