Micro- and Macro-Level Correlates of Adiposity in Children

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Context: Recently, studies using a social ecological perspective have identified important micro- and macro-level risk factors for excessive adiposity in youth. Although considerable research exists examining these relationships, few studies have applied a socioecological approach to simultaneously examine both micro- and macro-level factors in young children while objectively assessing adiposity via dual-energy x-ray absorptiometry (DXA). **Objective:** To examine race and sex differences in adiposity measured by DXA in a large sample of young children and to identify both micro- and macro-level correlates of adiposity. **Design:** Cross-sectional. **Setting and Participants:** Elementary school children (N = 495) from the southeastern United States participated. Anthropometrics, percentage body fat via DXA, and psychosocial variables via questionnaire were assessed in the Fall of 2003. Community-level sociodemographic data and built-environment variables via geographic information system were collected in Spring 2009. Data analyses were completed in the Spring of 2010. **Results:** Percentage body fat in white children was higher than in nonwhite children. Higher percentage body fat and poorer cardiovascular fitness were found in females compared with males. Percentage body fat was higher in children who had lower athletic competence and lived in neighborhoods with higher percentages of minority residents. **Conclusion:** This study provides preliminary support for the social-ecological model to explain variance in adiposity in children. Developers of health promotion programs for children living in minority neighborhoods should consider factors at multiple levels of the ecological model when designing and implementing programs.

KEY WORDS: **adiposity, social ecological model, youth**

J Public Health Management Practice, 2012, 18(5), 445–452

Childhood obesity is a growing global epidemic.[1] The prevalence of obesity in children has increased nearly 3-fold since 1980, with the highest prevalence of obesity observed in African American and Hispanic children compared with their non-Hispanic white counterparts.[2] As the risk of adult obesity is at least twice as high for obese children as for nonobese children,[3] it is crucial to identify factors contributing to the current epidemic of obesity in children to develop effective programs to prevent the early onset of obesity.

Recently, studies using a social-ecological perspective have identified important micro- and macro-level risk factors for obesity in youth.[4] Micro-level correlates refer to intra- and inter-individual characteristics, while macro-level correlates are sociocultural and environmental factors that directly or indirectly lead to accretion of excessive body fat.[5] At the micro level, biological and behavioral factors are positively associated with adiposity in children, such as poor fitness,[6] low levels of physical activity (PA),[7,8] and consumption of energy-dense foods.[9] Intraindividual factors such as psychological well-being,[10] self-esteem, and physical self-perception[11,12] are also associated with adiposity in

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No financial disclosures were reported by the authors of this article. This study was funded by the National Institutes of Health (DK063391).

The authors thank John Hanes and Janet Thornburg for coordination of data collection, Elizabeth Stewart for assistance with the data management, Dr Paule Barbeau for her consultation in data analysis and interpretation of study results, and the schools, teachers, and participants for their participation.

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DOI: 10.1097/PHH.0b013e31821dce0d

children and adolescents. Kimm et al[12] measured social acceptance, physical appearance (AP), and global self-worth (GSW) in African American and white children aged 9 to 10 years, and their results indicated that all 3 were inversely associated with the levels of adiposity.[12] At the micro level, interindividual factors such as low family socioeconomic status (SES),[13] lack of social support[14] and encouragement for PA,[15] and poor familial modeling[16] are associated with adiposity in children.

While the micro-level correlates of adiposity are subject to individual's control to a certain extent, the macro-level correlates represent environmental barriers that are beyond an individual's control and require actions at the policy level.[17] Obesity prevalence is higher in economically deprived neighborhoods as a function of macro-level factors such as lack of facilities and programming for safe and supervised PA[18,19] and restricted access to healthy foods.[20-22] Neighborhood built environment (eg, street connectivity and traffic safety) is another macro-level factor influencing obesity in US adolescents. For example, Ewing et al[23] found that children living in newly built "urban sprawling communities" were more likely to be obese, compared with those living in traditional residential communities. More recently, obesity status during young adulthood was found differentially related to multiple indicators of SES (social advantage, schooling, employment, and economic hardship) during adolescence in a sample of 11 250 young adults (mean age = 21.9 years) from the National Longitudinal Study of Adolescent Health.[24]

In epidemiological studies, obesity is typically assessed by using body mass index (BMI), which is calculated as weight in kilograms divided by standing height in meters squared (BMI = kg/m^2). In children, a BMI greater than 95th percentile for age and sex is considered obese and a BMI between 85th and 95th percentile for age and sex is regarded as overweight. While BMI is an easy-to-use indicator of obesity in large population studies, it does not provide true assessment of adiposity in young children.[25,26] Numerous recent studies have used dual-energy x-ray absorptiometry (DXA) to assess obesity, which provides an accurate and safe measurement of body composition by using a 3-compartment model (fat mass, fat-free soft tissue, and bone mineral content) in youth aged 8 to 20 years.[25,27] The percentage of the body made up of fat mass (%BF) is typically used as the index of relative fatness or excess adiposity. Body composition analysis with DXA has been shown to have high reliability and to be validity in children.[28]

A study by Yanovski et al[27] measured total fat in 20 pairs of African American and white girls aged 7 to 10 years who were matched on age, weight, BMI, and socioeconomic status and found that African American girls had less total fat measured by DXA and less visceral and subcutaneous fat measured by magnetic resonance imaging than white girls.[27] More recent studies using large representative data sets confirmed that African American and Hispanic children had lower %BF based on DXA compared with non-Hispanic white children.[29] These studies also found that BMI, as a measure of adiposity, becomes a more accurate and reliable predictor of adiposity at the high BMI range (BMI $\geq$ 85th percentile) after adjusting for age, sex, SES, and maturation status. These findings suggest that BMI may overestimate adiposity in lean youth.

In this article, the associations between adiposity and various micro- and macro-level factors are examined. Few prior studies have applied a socioecological approach to examine both micro- and macro-level factors in young children while assessing adiposity via DXA simultaneously.[17] We hypothesize that factors at both the micro and macro levels will be independently associated with adiposity in our present sample. Findings from this study will inform policy makers as they develop population-based programs to address the epidemic of childhood obesity.

Methods

Participants and procedure

The Medical College of Georgia FitKid Project (MCG FitKid) was a 3-year after-school prevention study aimed at the reduction of adiposity in young children. The rationale, design, and description of the intervention study are presented more fully elsewhere.[30] The present study presents baseline data collected in Fall of 2003, with additional secondary data retrieved in the Spring of 2009. Analyses were completed in Spring of 2010. The study protocol was approved by the human assurance committee at the Medical College of Georgia, and all participants and their parents/guardians signed informed assent and consent forms, respectively.

Eighteen elementary schools in Augusta, Georgia, participated in the study. Of the 617 participants who consented to be in the study, 600 were tested at baseline. One of the 18 county schools was a magnet school (ie, a specialist school), which draws students from all areas in the county. The nature of the school's admission policy and subsequent catchment area made it impossible to generate macro-level measures based on census block-group data; therefore, participants in this school (n = 44) were excluded from this study. An additional 61 participants were excluded because of missing adiposity data. A total of 495 participants from 17 remaining schools with adiposity measurement were included in the data analysis.

Measures

Body composition was assessed by DXA (Hologic QDR-4500W, Waltham, Massachusetts); DXA uses a 3-compartment model to assess fat mass, fat-free soft tissue, and bone mineral content, from which %BF was calculated. Since the test exposed participants to a small dose of radiation, all girls were tested for pregnancy before the DXA measurement. Height without shoes and weight with light clothes were recorded by using a Seca Wall Stop measuring unit (Seca Corporation, Hanover, Maryland) and a digital scale (Tanita Corporation of America, Inc, Skokia, Illinois). Both height (accurate to 0.1 cm) and weight (accurate to 0.5 kg) were recorded twice and averaged to produce the final value. The BMI was calculated as weight in kilograms divided by the standing height in meters squared (BMI $= kg/m^2$).

Micro-level correlates

Cardiovascular fitness (CVF) was assessed by the YMCA submaximal bench-stepping test.[31] The heart rate (beats per minute) at the completion of the test was used as the index of CVF. Higher heart rate indicated poor CVF. In the present study, CVF was significantly correlated ($P < .05$) with rest systolic blood pressure ($r = -0.23$), diastolic blood pressure ($r = -0.14$), high-density lipoprotein cholesterol ($r = 0.11$), waist circumference ($r = -0.46$), and %BF ($r = -0.55$).[32,33]

Global self-worth, athletic competence (AC), and perceived AP were assessed by the Self-Perception Profile for Children .[34] This multidimensional scale measures children's domain-specific perceptions of their competence and global perception of their self-worth.[34] For the present study, only GSW (a measure of self-esteem), AC (perceived competence in performing sport activities), and AP (perception of self-appearance during performing physical activities) subscales were administered to the participants. Studies have shown the SPPC to have adequate internal consistency. Acceptable internal consistency has been reported for children in third to fifth grade with Cronbach α of 0.78 for GSW, 0.80 for AC, and 0.80 for AP.[35]

Student demographics (race, sex, age, grade, and eligibility for free/reduced lunch) were obtained from the County Board of Education. Students in study schools were primarily white (35%) and African American (60%). We combined students in other racial categories (<5%: Native American, Hispanics, and Asian) with African American participants into a nonwhite group in data analysis, since there were no significant differences on the study measures.

Macro-level correlates

Home addresses of the participants were geocoded by using topologically integrated geographic maps from Maptitude (version 4.7, Caliper, Newton, Massachusetts). Published addresses of public and private PA facilities (eg, community recreation centers, tennis centers, martial art studios, and public parks) in the area were also geocoded. *Access to physical activity* was defined as the number of facilities within 0.5 miles (ie, a 10-minute walk) and within 3.0 miles (ie, driving distance) of the home address.[36] The proportion of students eligible for free/reduced lunch and the proportion of students belonging to a minority group at each school were obtained by using public-access databases. Neighborhood areas for each school were determined by using geographic information system, based on school boundary information provided by the County Board of Education Transportation Department. Sprawling indicators for a neighborhood area surrounding each school were obtained by using the overlay function in Maptitude based on the work of Ewing et al.[37] The neighborhood area was layered on the top of the 2000 US Census block-group level data. The derived values for a neighborhood area were based on the proportion of the block groups that were part of each neighborhood area. For instance, if 50% of the block group A was part of neighborhood area for school 1, 50% of the total population for that block group would be added as part of the total population of neighborhood for school 1. The derived values for gross population were used to determine the gross population density of each neighborhood area (population per square mile).[37] The street lengths (ie, average block length) were used to indicate street connectivity.[37] Family income per capita and percentage of household with income below poverty line were used as an index of neighborhood economic deprivation, determined from census block-group data for each neighborhood area.[37] Finally, schools were designated as either urban or nonurban on the basis of population density.

Analyses

Group comparisons were made on unweighted means by using 2 × 3 (sex by race) analysis of covariance, adjusting for age while accounting for school as a random effect. Pearson correlations were used to examine bivariate relationships among the key variables. A mixed-model analysis of variance was used to analyze the data from the children within schools by using a 2-level school effects model with %BF as the micro-level outcome in the analysis examined as a function of both micro- and macro-level factors. An unconditional means model was used to give an indication of the clustering of baseline %BF within the schools (model 1). The intraclass correlation of baseline %BF was calculated by using this intercept-only model that estimated the between- and within-school variation. Macro-level correlates analyzed were neighborhood street connectivity, neighborhood population density, percentage of minority population in the neighborhood, neighborhood family per capita income, percentage of minority students in each school, percentage of children eligible for free or reduced lunch in each school, and geographic location of schools. Since these macro-level correlates tended to be correlated, they were first entered in the model separately. All significant correlates were then entered together in a model (model 2). Child-level correlates that were considered as part of a base micro-level model were age, race (white and nonwhite), sex, eligibility for free or reduced lunch (yes or no), and interaction terms (model 3). The CVF, GSW, AC, and PC were added to model 3 subsequently (model 4). Only significant correlations were reported. The amount of within-school variation accounted for after each addition of a child-level variable was calculated. Heterogeneity of the relationships of the SPPC variables across the micro-levels of ethnicity and sex and macro-levels of schools was explored. A model that contained both micro-level and macro-level predictor variables was constructed (model 5). Only significant factors were retained in the model. Statistical significance was set at $\alpha = .05$. SAS version 9.1.3 (Cary, North Carolina) was used for all analyses.

Results

Table 1 describes the adiposity, micro-level correlates of adiposity as well as residence, and access to PA facilities in the study sample and subgroup comparisons. Percentage body fat was greater in females compared with males, and whites compared with nonwhites. There was a trend, although not significant, that white females had the highest %BF, while nonwhite males had the lowest %BF. It should be noted that there was no sex or race differences in body weight or BMI. Cardiovascular fitness was significantly higher in males than in females. Scores for AP were higher in males than in females and higher in nonwhite than in white students.

Nonwhite students were significantly more likely to be eligible for free or reduced lunch and have greater access to PA facilities within 0.5-mile distance from their residence than whites; nonwhites were also more likely to attend school in urban areas. Finally, medians and ranges of geocoded macro-level correlates are presented in Table 2. There were considerable variations in most of the measures, which reduced the proportion of variance accounted for by the school.

Results of mixed-model analysis on %BF are presented in Table 3. The %BF was independently and significantly associated with the percentage of minority students in each school ($b = -0.06$, SE = 0.02), neighborhood population density ($b = -0.001$, SE = 0.0004), nonurban school location ($b = 2.70$, SE = 1.20), percentage of minority population in neighborhood ($b = -0.07$, SE = 0.03), and neighborhood per-capita family income ($b = -0.02$, SE = 0.001). When all significant macro-level correlates were entered in the model together (model 2), only percentage of minority population in neighborhood remained significant. In the base micro-level model (model 3), higher level of %BF was significantly associated with students being nonwhite and female. In model 4, lower levels of CVF and AC were significant predictors of %BF when added to model 3. All significant micro- and macro-level correlates were entered together in model 5. Higher %BF was significantly correlated with being female, lower levels of CVF, lower levels of AC, and lower percentage of minority population in the neighborhood.

Discussion

We found that %BF in white children was higher than in nonwhite children (predominantly African American) in our study sample. This finding is consistent with the results of published studies with large samples, which assessed adiposity by using direct or indirect measurement of body fat.[38] On the contrary, body weight and BMI were not significantly different between white and nonwhite participants in our study sample. Previous studies have found difference in BMI between white and nonwhite (eg, African American, Hispanic, and Native American) children.[2] In these studies, African American children have usually been reported to have higher level of BMI,[39-41] but these participants were older (by 2 to 5 years) than those in the present sample. Since DXA is a more accurate measure of adiposity than BMI, it is crucial to examine this finding by using a larger sample of children.[26,38] Several large randomized trials have reported significant changes in PA and dietary behaviors as well as environmental supports but failed to detect BMI differences between intervention and control groups.[42,43] In our randomized obesity studies in children, we have found significant reduction in %BF and waist circumference but nonsignificant effects on weight and BMI.[32,33,39] The present findings may help to explain some of the nonsignificant intervention effects observed for BMI in previous intervention studies.

TABLE 1 ● **Descriptive Information of Adiposity, Micro-Level Correlates of Adiposity as Well as Residence and Access to PA Facilities in the Study Sample and Race by Sex Subgroup Comparisons[a,b]**

	White		Nonwhite		
	Males N = 76	Females N = 83	Males N = 160	Females N = 176	Group Comparison
Age, y	8.7 (0.6)	8.7 (0.5)	8.8 (0.6)	8.7 (0.6)	NS
Height, cm	132.6 (6.4)	130.7 (6.9)	134.1 (7.6)	134.1 (7.4)	↑ Age[c] NonW > W[d]
Weight, kg	34.2 (11.5)	32.9 (10.5)	34.4 (10.0)	35.6 (11.8)	↑ Age[d]
Body fat, %	25.9 (9.1)	30.5 (8.5)	22.5 (8.9)	28.2 (9.0)	W > NonW[d] F > M[c]
Body mass index, kg/m^2	19.1 (4.7)	18.9 (4.4)	18.8 (3.9)	19.5 (4.8)	NS
Cardiovascular fitness (heart rate, beats per minute)	159 (16)	165 (17)	155 (17)	163 (18)	F > M[c]
Free/reduced lunch, n (%)	31 (41)	34 (41)	107 (67)	132 (75)	NonW > W[c]
Global self-worth	3.2 (0.7)	3.3 (0.6)	3.1 (0.7)	3.3 (0.6)	NS
Athletic competence	3.1 (0.8)	3.2 (0.7)	3.1 (0.6)	3.2 (0.6)	NS
Physical appearance	2.9 (0.7)	2.7 (0.6)	3.0 (0.6)	2.8 (0.6)	↓ Age[d] M > F[c] NonW > W[e]
Number of PA facilities within 0.5 mi	0.4 (0.9)	0.3 (0.9)	0.4 (0.9)	0.5 (0.9)	NS
Number of PA facilities within 3.0 mi	7.4 (7.7)	6.0 (8.1)	12.4 (8.6)	12.8 (8.7)	NonW > W[c]
Rural residency, n (%)	25 (32)	26 (29)	105 (61)	129 (63)	NonW >W[c]

[a]Data were collected in Fall 2003.
[b]Mean (SD) unless otherwise noted; ↑ Age, increase with age; ↓ Age, decrease with age; NonW, Nonwhites; W, whites; M, males; F, females; PA, physical activity.
[c]$P < .0001$.
[d]$P < .01$.
[e]$P < .05$.

We found higher %BF and poorer CVF compared with males. While previous studies have found sex differences, which occurred during and after puberty,[44,45] the average age of participants in this study was 8.7 years, suggesting that whatever social or biological factors are contributing to these sex differences are acting at an earlier age in the present sample. Unfortunately, we were unable to assess pubertal staging in the current study. An additional finding was that CVF was negatively associated with adiposity, which is consistent with the literature. For example, Gutin et al[46] found that CVF accounted for 36% of variance in %BF after controlling for race, sex, and age in adolescent males and females. Although a considerable portion (30%-50%) of CVF is genetically determined,[47] experimental studies have consistently demonstrated that increased participation in PA led to significant increases in the fitness of children.[39] The implication of our finding is that prevention of obesity in children must focus on the promotion of participation in regular PA and early prevention of obesity in young girls, since obesity is known to track into adulthood.[48]

Our results indicated that lower level of AC was significantly related to higher %BF. A recent study of Australian children by Franklin et al[49] found a similar relationship between adiposity and AC. However, the present study utilizes a more comprehensive model to control for potentially confounding variables, thus providing a more robust test of the relationship. This finding highlights the importance of providing developmentally appropriate and enjoyable PA programs to develop competency and intrinsic motivation in youth. Recently released standards for

TABLE 2 ● **Median, Minimum, and Maximum of Macro-Level Measures (N = 17 schools)[a]**

	Median	Minimum	Maximum
Unconditional means model			
Students receiving free/reduced lunch, %	67.5	33.0	95.0
African American student, %	57.5	21.0	100.0
Street connectivity, miles	0.11	0.07	0.20
Population density, no. of persons per mi^2	2070	111	4924
Minority population, %	44.6	21.9	97.3
Family per capita income, $	51 429	9095	359 599
Population in poverty, %	13.6	5.9	38.4

[a]All data were collected Fall 2003.

TABLE 3 ● **Parameter Estimate (SE) of Micro- and Macro-Level Correlates of Adiposity (%BF)**

	Model 1	Model 2	Model 3	Model 4	Model 5
Fixed effects					
Intercept	26.4 (0.7)[a]	29.8 (1.7)[a]	22.2 (6.3)[c]	22.8 (5.3)[a]	25.2 (5.4)[a]
Age, y			0.7 (0.7)	0.6 (0.6)	0.6 (0.6)
Race[b]			2.3 (0.9)[d]	1.2 (0.8)	0.9 (0.6)
Sex[b]			−5.3 (0.8)[a]	−3.4 (0.7)[a]	−3.4 (0.7)[a]
CVF, beats per min				0.27 (0.02)[a]	0.27 (0.02)[a]
Athletic competency				−1.9 (0.5)[c]	−1.93 (0.5)[c]
Random effects					
Minority population, %		−0.07 (0.03)[d]			−0.058 (0.029)[d]
Between school		3.5 (2.2)			2.5 (1.5)
Within school		82.2 (5.3)			53.1 (3.4)
Goodness of fit					
−2 log likelihood		3601.1			3385.6
Akaike information criterion		3609.1			3403.6

Abbreviations: %BF, percentage of the body made up of fat mass; CVF, cardiovascular fitness.
[a] $P < .0001$.
[b] $P < .001$.
[c] Nonwhite was the reference for race comparisons; female for sex comparisons.
[d] $P < .05$.
Model 1, unconditional means model; model 2, model 1 + macro-level correlates; model 3, model 1 + age + race + sex; model 4, model 3 + CVF + athletic competence; model 5, model 2 + model 4.

after-school PA have highlighted these recommendations for young children.[50]

We also found that %BF was lower in neighborhoods with higher percentages of minority youth in the multivariate mixed-models analysis, in addition to similar bivariate relations. This finding is not surprising, since the majority of the minority children in our study sample were African American who had lower %BF compared with their white counterparts. Miech et al[13] found that a higher prevalence of obesity (assessed as BMI) was associated with living in economically deprived neighborhood after controlling for individual race, sex, and SES in adolescents.[13] When we replaced %BF with BMI in our analysis models, we found similar but weaker relations between BMI and micro- and macro-level covariates (data not shown). A plausible explanation for this inverse relation is that nonwhite students resided mostly in urban neighborhood and had greater access to PA facilities, which allowed them to be more active, compared with white students.[51]

There were several limitations in this study. First, this study was cross-sectional in design; therefore, the relationships examined in this should be interpreted with caution since they could not demonstrate causality. Second, we did not have objective measures of PA or dietary behavior, which are the primary etiologic pathways for obesity in children. Third, young children may have had difficulty comprehending the questions on the questionnaires. However, we utilized measures that have been validated in children and found acceptable internal consistency in their responses in the current sample. Finally, although we had a relatively large number of participants in the study, we only had 17 schools, which might have reduced the statistical power to explore the relationships between adiposity and macro-level correlates.[52]

The study had 2 major strengths that could make it an important contribution to the literature. First, it tested a social-ecological model of childhood adiposity while employing measures at the micro and macro level. Few have attempted this approach.[17,53] This study demonstrated that it was feasible to test the model with both micro- and macro-level factors, separately and additively. Second, adiposity was measured by DXA in a relatively large sample of children. Previous studies have typically used BMI as measure of overweight to test its relationships with social-ecological factors. Findings from this study raise 2 important and timely issues. First, given that BMI-based measures do not provide valid assessment of adiposity, researchers should employ techniques such as DXA or bioimpedance to determine the impact on adiposity of childhood obesity-prevention trials. Second, racial/ethnic difference in obesity from epidemiological studies that rely exclusively on BMI should be interpreted with caution, especially in younger populations.

In conclusion, this study provided preliminary support to the social-ecological perspective in explanation of variations in adiposity in children. The study findings suggest that children's gender is an important factor in designing programs for obesity prevention in children; children should be provided with regular PA opportunities, with a focus on developing their competence in sports and motor skills.[54] Finally, researchers should investigate and replicate the findings on racial inconsistency of adiposity found in this study.

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