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An ecologic analysis of socioeconomic and environmental determinants of overweight and obesity prevalence among US adolescents using Bayesian small area estimation with 2003 and 2007 National Survey of Children's Health

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Degree to be awarded: Master of Public Health

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By Jessica N. Cook-Smith, B.S.

Objective: Childhood obesity continues to be a growing public health concern with 12.5 million (17%) school-age children and teens affected.[1] We aim to predict county-level overweight and obesity prevalence among U.S. adolescents with Bayesian small area estimation.[2] Using data from the 2003 and 2007 National Survey of Children's Health, we will explore the association of adolescent overweight and obesity prevalence with sociodemographic and physical environment characteristics.

Methods: We used a Bayesian hierarchical Poisson model based on the Markov chain Monte Carlo (MCMC) approach to estimate the county-level prevalence of childhood obesity nationwide. Negative binomial Poisson regression models will be used to perform an ecologic analysis of social and environmental determinants of health on adolescent overweight and obesity prevalence. Both the small area estimation and the county-level contextual analysis were performed for three excess weight prevalence outcomes: overweight including obesity, overweight alone, and obesity alone.

Results: Using small area estimation, 30.7% of US adolescents are overweight or obese. The South region and East South Central Census division have the highest prevalence. The geographic disparities differ when examining overweight and obesity separately. An increased risk of excess weight among adolescents is associated with certain county-level indicators of poor adult health, poor socioeconomic environment such as child poverty rate and high unemployment rates, home and school food assistance and racial composition.

Conclusions: The model-based childhood obesity prevalence estimates displayed a geographic pattern similar to that of adult obesity prevalence. Higher prevalence was predominantly seen in the southeast and in counties with indicators of poor social and physical environment and increased food assistance. The prevalence varies across and within states and contextually by county suggesting an opportunity for intervention at the local, state and national level. These results suggest that childhood obesity is a complex and multi-faceted issue and may be influenced by the combined effects of the social, economic and physical environments.

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ABBREVIATIONS

ACS—American Community Survey

BLS—Bureau of Labor Statistics

BMI—Body Mass Index

CDC—Center for Disease Control and Prevention

FBI—Federal Bureau of Investigation

FFFI—Fresh Food Financing Initiative

FIPS—Federal Information Processing Standard

HRSA—Health Research and Services Administration

IOTF—International Obesity Taskforce

IOM—Institute of Medicine

MCHB—Maternal and Child Health Bureau

MCMC—Markov chain Monte Carlo

NCHS—National Center for Health Statistics

NCS—National Children's Study

NSCH—National Survey of Children's Health

SAIPE—Small Area Income and Poverty Estimates

SD—Standard deviation

SES—Socioeconomic status

SGA—Small for gestational age

SLAITS—State and Local Area Integrated Telephone Survey

USDA—United States Department of Agriculture

USDE—United States Department of Education

WHO—World Health Organization

CHAPTER 1: Literature Review

Childhood obesity continues to be a growing public health concern with 12.5 million (17%) school-age children and adolescents affected.[1] Prevalence rates of obesity among children have begun to plateau after nearly tripling since the 1960s.[1] From 2003 to 2007, the national *overweight including obesity* and *obesity alone* prevalence among children increased 3.6% and 10.4%, respectively.[3] Even though the trends of prevalent overweight (85^{th} percentile $\leq$BMI<95^{th} percentile) and obese (BMI$\geq$$95^{th}$ percentile) children may be leveling off for some U.S. and European populations, the most obese are becoming heavier.[1,4]

There is a need to develop effective policy to combat the growing population of overweight and obese children in our nation. This requires better knowledge about which individual, family and environmental characteristics are important. Currently, there is no source for nationwide county-level overweight and obesity prevalence estimates for children and adolescents. This study uses a Bayesian small area estimation model to predict county-level prevalence for US counties based on 2003 and 2007 National Survey of Children's Health (NSCH) survey data. These small area estimates are then regressed on county-level contextual variables to identify potential ecologic correlates of high and low childhood obesity prevalence.

The State of Pediatric Obesity

Obesity has a negative impact on an individual's health and economically on the nation's health care system. There is an increased risk for obese children to carry this excess weight into adulthood and for adverse health outcomes during childhood and into adulthood.[5,6] Some studies suggest that 70% of obese children have at least one additional cardiovascular risk factor, and 30% have two or more such as heart disease and diabetes.[7] Poor health outcomes in adulthood have been associated with childhood obesity even if obesity did not persist.[8,9] A higher rate of mortality in young and middle adulthood is associated with childhood obesity as well as persistent obesity and chronic disease comorbidities.[9-12] However, the prevalence is quite low and has only been observed in severely obese children (BMI-for-age at or above the 97^{th} percentile).[7,9] In addition to contributing to the adverse health outcomes of high BMI, obese adolescents are at a greater risk for low self-esteem and body dissatisfaction.[13] Similar findings show an increased risk of anxiety and depression among obese children and adults, which may be a consequence of stigma and discrimination.[14,15]

According to 2009-2010 NHANES data for the adult population (those older than 20 years of age), the *overweight including obesity* (BMI at or above 25) prevalence is 69.2%, the *obesity alone* (BMI at or above 30) prevalence is 35.9% and the extreme obesity (BMI at or above 40) is 4.9%.[16] The prevalence of *obesity alone* among adults is twice that observed in children, where some studies suggest that from 25% to 70% of obese adults were obese during childhood.[17,18] Children with higher body mass indices and at older ages are more likely to be obese as an adult. The risk of obesity persisting into adulthood increases for older children, severely obese children and children with at least one obese parent.[19,20]

With 73 million obese men and women carrying an extra 24 pounds than the average adult did in 1960, the costs associated with obesity-related care have increased substantially.[1,21] The care associated with overweight and obesity results is a high economic burden to families and society. Obesity and its chronic disease co-morbidities are estimated to be responsible for 26,000 to 300,000 excess deaths per year, yet most estimates range from 100,000 to 200,000 deaths.[22-27] Medical care for obesity-related conditions now accounts for 9.1% ($177 billion) of all health care spending up from 6.5% ($78.5 billion) in 1998 for adults.[28-31] Childhood obesity is estimated to cost $14.1 billion for prescriptions, emergency room, and outpatient costs as well as $237.6 million for inpatient cost annually.[32,33] In 2006, the average obese person spent 42% ($1,429) more on medical care than a normal weight person.[34] If current trends continue, over 40% of adults will be obese by 2015 with projections among children to nearly double (>30%) by

2030.[35-37]

Mirroring this increasing trend of pediatric obesity is a predicted increased prevalence of diabetes, liver and heart disease among obese children combined with persistent obesity into adulthood.[38-40] The prevalence of overweight and obesity among U.S. children differs geographically (both regionally and by urban/rural status) by socioeconomic and demographic characteristics. Childhood overweight and obesity research has shown an association of excess weight with poor diet, reduced physical activities, socioeconomic and demographic characteristics, and social and built environment factors. [8,9,19,41-44]

Socioeconomic and Demographic Disparities

In the early twentieth century, excess weight had been associated with increased wealth and health, and remains so in some parts of the world; however, an inverse relationship has been observed in overweight and obesity trends among US adult populations in the latter half of the 20^{th} century.[16,45,46] From 2003 to 2007, there was a 10% increase in the overall national childhood *obesity alone* prevalence with even larger increases among certain socioeconomic and demographic subpopulations especially among minority and low-income populations.[3]

Obese children are more likely to be from low-income households with greater disparities among certain race-ethnicity and sex subpopulations.[1,21,47] There was a 23-33% increase in the *obesity alone* prevalence and 13-15% increase in the *overweight including obesity* prevalence among children in low-education and low-income households from 2003 to 2007.[48] Research shows a lower *obesity alone* prevalence among non-Hispanic black girls living in a high-education (greater than high school education attainment) household compared to non-Hispanic black girls living in households with only a high school education (19.4% vs. 29.6%).[1] Children living in non-English speaking, single mother, and high unemployment households are at an increased risk for overweight and obesity.[48] The largest increase in obesity prevalence since 1980 is among Americans living below 200% of the poverty level.[4] The structural inequalities of living in poverty during childhood and adolescence may translate to living under similar conditions as an adult. Excess weight as an adult is associated with lower socioeconomic status (SES) during childhood such as neighborhood poverty and low parental education.[49] Another study has shown an association of childhood poverty among young adult obese women but not men.[50]

The prevalence of *overweight including obesity* has increased for non-Hispanic White, non-Hispanic Black, and Hispanic children since 1971.[51] Yet, there is a higher prevalence of *obesity alone* among Hispanic children compared to white children at all ages.[1,4] One study suggests a lower *obesity alone* prevalence for Asian adolescents compared to other race-ethnicity groups.[52] Some evidence suggests that minority groups especially non-Hispanic Blacks are more likely to remain obese over time.[53]

Current childhood obesity literature demonstrates that further disparities exist by age and sex. Older adolescents and teens have an increased risk of obesity compared to toddlers.[1] The overall average obesity prevalence is similar for boys and girls but sex disparities have been observed in some racial/ethnic groups.[54] Hispanic boys and non-Hispanic Black girls have a marked increased risk of obesity compared to their white counterparts.[1,54-57] Many of these socioeconomic and demographic disparities in childhood overweight and obesity prevalence persisted even after adjusting for behavioral factors such as physical activity and electronic media use.[48]

The measurements of excess weight for children

Obesity refers to an excess of body fat (adiposity) and overweight is defined as a weight that is greater than a designated weight standard. The first pertains to the accumulation of too much adiposity in the body whereas overweight describes an outward appearance that possibly violates an accepted norm. Excess weight has consistently been shown to be the result of an energy imbalance yet the exact cutoff at where the extra weight becomes physically taxing is less clear. Poor diet and physical inactivity is associated with an increased risk of obesity among adults and children.

The most common approach for measuring overweight and obesity is body mass index (BMI) which is a non-diagnostic, screening tool to estimate body fat by dividing weight in kilograms by the square of height in meters. Advantages of using BMI include its low cost, reproducibility and ease of interpretation for both clinical and non-clinical audiences. The development of this tool is rooted in astronomy in the 1830s where the Quetelet index was originally constructed by a statistician for use on adult, not child, populations. BMI was later implemented in the early 1900s for its ease of use and strong predictability of adiposity using height and weight.[58] Interestingly, neither of these height-weight indices were created to be a gauge of individual health.[59]

Even though BMI is a simplistic method to obtain body weight measurements, it is problematic in many ways especially with children.[60,61] BMI varies by age and sex for children and requires an age- and sex-specific measurement to account for unique growth patterns. Yet, the BMI percentile may not represent the same percentage of adiposity for different race/ethnicity groups among children.[4,43,62] Some studies have indicated that non-Hispanic black children have lower body fat and higher lean body mass when compared to non-Hispanic white and Mexican American children at equivalent BMI measurements.[4,63] This difference in body fat-to-lean body mass proportion may be associated with a difference in risk for obesity and other adverse health outcomes by race-ethnicity. Variation may also occur as a result of measurement error (both as a result of improperly calibrated equipment and observer bias), biological and physiological change in the child, and seasonal growth differences.[61]

The cutoff values used with BMI are not diagnostic criteria but rather an indirect measurement which may indicate an increased risk for adverse health effects associated with high adiposity. It should be noted that the terminology used in overweight and obesity studies varies considerably. The CDC and World Health Organization (WHO) replaced the 1997 U.S. National

Center for Health Statistics (NCHS) reference with new child growth charts in May 2000 and April 2006, respectively.[64] Originally, the 2000 Center for Disease Control and Prevention (CDC) Growth Charts used *at risk for overweight* to represent the 85th-95th percentile and *overweight* as at or above the 95th percentile of BMI-for-age and-sex.[65] More recently, the Institute of Medicine (IOM) Committee on Childhood Obesity Prevention modified the terminology to be functionally similar with the definition used in adult populations.[66] As defined by CDC for use with US pediatric populations, *overweight alone* is a BMI at or above the 85th percentile but less than the 95th percentile, while *obesity alone* is at or above the 95th percentile. [65,67] Many childhood overweight and obesity studies examine risk factors among the total population with excess weight that is overweight *and* obese children which is commonly referred to as *overweight including obese*, where BMI is at or above the 85th percentile. These measures are each age- and sex-specific for children under 18 years.[65] The weight categories—*overweight alone, obese/obesity alone,* and *overweight including obese/obesity*—as defined above, will be used throughout this chapter to appropriately identify the statistics being used.

Variability may arise from the use of differing reference data and cutoff values to define excess weight categories among pediatric populations, which typically results in slightly inconsistent prevalence estimates.[65,67] The CDC growth chart definitions are used in the United States. Worldwide, the WHO Child Growth Standards are used, where the cut points were developed at an International Obesity Taskforce (IOTF) workshop, and are quite similar to the U.S. definition for identifying overweight and obesity among children and adults.[61] Even with similar cutoffs, the two charts differ for several measurements at different stages of childhood.[64] Some research suggesting increased mortality among high BMI adolescent populations is still within the bounds of statistical uncertainty until an individual has surpassed a BMI of 40.[68] This research has been inconsistent and it remains unclear as to what specific BMI cutoff values or some other adiposity/excess weight measurement is associated with an increased risk of adverse health outcomes during childhood and into adulthood.[20,61]

BMI is useful to measure the proportionality of height to weight but not to directly measure body fat or predicting mortality.[69] Since it has been suggested that fat distribution is a better mortality predictor, other weight quantification methods such as measurements of waist circumference, skinfold thickness, or bioelectrical impedence analysis may be superior.[70] However, little research has been performed on the practicality of using these alternative measures in the clinical setting especially for pediatric populations.[61] Today BMI is the most commonly used measurement for height and weight in clinical, public health and community-based screening programs.

Genetic, Parental and Early Life Exposures Promoting Childhood Obesity

Many studies have attempted to identify the mechanisms, or causal pathways, that may predict childhood obesity. Suggestions include biologic hypotheses related to 'lifecourse epidemiology', genetic factors, maternal behaviors during and after pregnancy, and birth outcomes. The human body has an evolutionary predisposition to store excess calories in the event of famine. However, this 'thrifty gene' may be problematic in a free market-based economy with an excess of inexpensive nutrition-poor, calorie-dense food choices paired with an overall reduction in energy expenditure.[71] Evidence suggests that genetic factors may account for as much as 70% of each individual's variation in adiposity.[72] Lifecourse epidemiology, more specifically the Barker hypothesis, suggests that poor prenatal nutrition may influence the fetus's development and growth (fetal programming) resulting in a greater risk for chronic disease after birth including pediatric obesity.[73,74] An early life, high caloric diet commonly prescribed to small for gestational age (SGA) babies has been associated with an increased risk of obesity.[75] Greater pregravid (pre-pregnancy) and gestational maternal weight gain is associated with an increased risk of children developing obesity.[76] Maternal diabetes is associated with childhood obesity regardless of birth weight.[77] However, it is difficult to differentiate between social and genetic influences to examine the effect of a nutrition-poor food environment and/or an inherited propensity for adiposity.

Maternal smoking during pregnancy has been linked to an increased risk of low birth weight, SGA, or preterm which have all been associated with childhood obesity.[73,74,78] With adult smoking rates of rural residents 32% higher than urban counterparts, it may be possible that the rate of maternal smoking during pregnancy is also higher among rural mothers, partially contributing to geographic variation.[79,80] Presence and longer duration of breastfeeding has been suggested as protective against childhood obesity when compared to early introduction of juices and solids.[81,82] Higher maternal smoking prevalence, lower rates of breastfeeding initiation and reduced breastfeeding duration among rural mothers may potentially explain some of the rural/urban differences of childhood obesity.[83,84]

Risk of childhood obesity varies depending on who is the primary caregiver. Parental, especially maternal, obesity has been suggested as one of the strongest non-health behavior predictors of childhood obesity with some studies reporting a doubling of the risk of obesity for children with obese as compared with non-obese mothers.[85,86] Grandmother as primary caregiver has been associated with increased risk of obesity among grandchildren under her care.[87] It is possible that head of household type and home food environment may differ in rural, suburban and urban communities.

Changing dietary habits and lifestyle behaviors

There has been a general shift in the United States towards increased snacking and portion sizes, more convenient foods usually higher in fat and calories, increased electronic media use, decreased physical exercise associated with advancing technology and vehicular transportation; all of which have been consistently linked with increased risk of childhood obesity. The two strongest predictors of childhood obesity, physical inactivity and poor nutrition, have been associated with the built environment which influences available opportunities for physical exercise and access to food.[88] Several regional rural childhood obesity studies have found associations where less than recommended levels of physical exercise and nutritionally important foods combined with high levels of television viewing and increased sugar-sweetened beverage consumption results in an increased risk of obesity for children of all ages.[89-92] Evaluations of nutrition-poor food environments during childhood both at home and at school have shown positive associations with an increased risk of childhood obesity. It has been suggested that childhood obesity is associated with available meal and snack (vending machine items) choices, as well as proximity of convenience stores and fast food restaurants to the school campus.[93,94] One study had shown that students purchase more than 350 calories worth of foods and beverages before or after school at convenience stores when accessible from school.[95] Snacks comprise nearly a quarter of an average American child's diet.[96] It has been suggested that the portion size of meals account for nearly 20% of the variability in diet.[97] One-third of school-aged children eat at fast food restaurants and typically consume meals that are more calorie-dense compared with children who do not eat fast food.[98] A lower BMI is associated with children who eat breakfast compared to those who forego this important early morning meal.[99-102] On average, school-age children spend at least 6 hours and consume at least one meal per day at school.[103] Research has shown that children attending public schools and/or schools with poor vending machine choices and serve French fries more than once a week are more likely to be obese.[104,105]

At least half of U.S. adolescents and teenagers do not meet physical exercise recommendations with 25% reporting no exercise at all.[106] Predictors of physical inactivity include high electronic media use (television watching, video game playing, and computer activities), older age (15-17 years), female gender, and inactive parents.[107,108] It is estimated that school-age children spend approximately 3.5 hours per day watching television with more hours logged among low-income and minority children.[109] Among adults, racial differences are observed where non-Hispanic blacks and Hispanics are less likely to engage in regular physical exercise than their non-Hispanic white counterparts.[110] It is possible that this physical activity pattern among adults is mirrored in children. Physical activity levels among children substantially decrease as they age, with young children more likely to meet recommended physical activity guidelines than adolescents and teens.[111] Boys were slightly more active than girls at all ages.[111] Increased physical activity levels among adolescents is positively associated with maternal age, parental income status and living in a higher socioeconomic neighborhood.[112,113]

Geographic Patterns of Pediatric Obesity

There are several studies showing that the geographic pattern of high body mass index varies across the US by state using 2003 and 2007 National Survey for Children's Health (NSCH) data. A total of 20 states had an *overweight including obesity* prevalence above the national average in 2003 and 2007, 30.6% and 31.6%, respectively. The prevalence of *overweight including obesity* ranged from 20.9% (Utah) to 39.6% (District of Columbia) in 2003, and from 23.1% (Minnesota) to 44.5% (Mississippi) in 2007. There were 18 and 16 states with an *obesity alone* prevalence above the national average (14.8% and 16.4%) in 2003 and 2007, respectively. The prevalence of *obesity alone* ranged from 8.5% (Utah) to 22.8% (District of Columbia) in 2003, and from 9.6% (Oregon) to 21.9% (Mississippi) in 2007.[3] Note that the number of states surpassing the national prevalence remain the same or decrease but the change in prevalence increased for both *overweight including obesity* (3.6%) and *obesity alone* (10.4%) prevalence among US adolescents (10-17 years old) from 2003 to 2007. A regional trend is observed with a higher prevalence of *overweight including obesity* in Southern states (21.9% to 44.5%) compared to the Western region (9.6% to 23.1%).[3,114,115] The Southeastern region is home to 10 of the 11 most obese state populations with Mississippi as the highest for the last six years.[92,114-116] This inter-state pattern of childhood overweight and obesity prevalence is similar to that observed among the US adult population.[117,118] There is an increased prevalence of *obesity alone* across states for non-Hispanic Blacks and residents of the South and in the Midwest among adult populations.[118,119] More than 40% of the US pediatric population resides in the South which disproportionately had the highest *overweight including obesity* prevalence (17.5%).[108] Some evidence suggests that high body mass index prevalence is rising faster than normal in some rural communities in Pennsylvania, New Mexico, Michigan, West Virginia, Georgia, and North Carolina.[120-122] This geographic pattern in the prevalence of overweight and obesity in rural areas may be associated with an increase in minority subpopulations, seasonal work and unemployment rates.

These regional differences in the prevalence of excess weight among children exists within states as well as across states and may be explained by socioeconomic and demographic characteristics such as gender, race, education, health insurance status/type and SES.[123,124] Among rural residents, non-Hispanic Black children have the greatest risk of obesity compared to all other race/ethnicity groups.[119,122] The burden of increased high body mass index prevalence among non-Hispanic Blacks is consistent for both rural and urban communities. Non-Hispanic black children and those from a low-income household were more likely to be overweight or obese across states. Yet, the *overweight including obesity* and *obesity alone* prevalence differed within states by insurance, income and race/ethnicity groups across states. For instance, Pennsylvania is ranked 23rd for overall childhood *overweight including obesity* prevalence but is the lowest in the nation among low-income children.[114] Intra-state variation is also observed by insurance type (private vs. public) and race/ethnicity. There is an increased risk of obesity among publicly insured adolescents (10-17 years) compared to their privately insured counterparts.[115]

Rural/urban differences

Rural children are more likely to be non-Hispanic White, uninsured, live in families with low-income and low-educational attainment than urbanite children.[108] Structural barriers that exist for rural residents include poor access to health care, less varied access to food choices, lack of health and nutrition education and overall limited resources.[123-126] This lack of resources and limited food access exacerbates the obesity-promoting behaviors most commonly associated with high body mass index such as diet and physical activity. Rural residents have an increased risk of obesity when compared to their urban counterparts, 23% versus 20%, respectively, for adult populations.[122] It has been suggested that this urban/rural disparity is similar for rural children where they are 25% more likely to be overweight or obese than their urban counterparts (16.5% vs 14.3%).[1,47,89,90,92,127-129] It is likely that the prevalence will also vary when compared to suburban areas and communities with ghettoization and high levels of residential segregation.

Current US lifestyles that are characterized by reduced physical exercise, sedentary work, and low-quality, high-fat, high-calorie diets have been associated with an increased risk of obesity. Implications of these obesity-promoting health behaviors have been confirmed with several regional rural obesity studies even if one might assume for a rural lifestyle to be a more active one. These results indicated that living in a rural area is associated with increased risk of becoming overweight or obese through culturally-associated determinants such as higher dietary fat and calorie consumption, lower rates of physical exercise, and greater than recommended television viewing time which may be associated with larger proportions of the childhood population having a BMI over the 85^{th} percentile (overweight).[89,90,127,128]

Research suggests that rural diets can be as poor as urban diets but rural diets are more likely to be high in sugar and fats while low in fruits in vegetables where only 25% of rural Blacks meet the USDA requirement for fruits and vegetables.[127,130,131] These dietary inadequacies may be explained by reduced access to supermarkets which has been associated with decreased fruit and vegetable consumption and poor overall diet and nutrition.[132] The majority of evidence suggests higher BMI and lower physical activity levels among rural adults compared to their urban counterparts.[92,133] However, the results of studies examining this association in children have been inconsistent. A more recent study suggests that urban children are more likely to be inactive than children in rural areas; consistent across most key demographic characteristics.[108]

How is Childhood Obesity Sustained?

Obesity has been attributed to energy intake-expenditure imbalance; however, there are many factors that create an obesogenic environment. These include characteristics of food, physical, economic and psychosocial environments which may be unique to an area, a population and a disease. There have been major shifts in the means of food acquisition and energy expenditure including vehicular transportation, reduced physical activity programs in school, and more sedentary work settings. The relationship of the effect of physical inactivity on overweight and obesity prevalence is likely multi-dimensional needing to account for diet, genes, and environmental factors. This relationship may be even more complex for children. Minority children are more likely to live in areas of low-income and/or poverty and to reside in neighborhoods of limited food resources and poor built environments.[134] It has been hypothesized that many negative built, physical and social factors may collaboratively discourage physical activity. Urban neighborhoods, especially those in the inner city, are more likely to have higher crime rates, poorer walkability, reduced perceived safety, limited food access, and/or lack of park or recreation resources.

Food Environment

Food insecurity is associated with overweight and obesity and is more common in low-income households.[135] Women with children are at a greater risk compared to women who are not mothers and food insecure fathers.[136] There is reduced availability of nutritionally important foods in the most socioeconomically disadvantaged inner portions of towns and cities (urban cores), and in remote rural areas.[137] Presence and number of supermarkets increase in neighborhoods as household income increases which sometimes results in poorer neighborhoods being more reliant upon convenience stores and fast food restaurants.[138] Lack of supermarkets in low-income, minority neighborhoods may negatively affect the health of its residents. Supermarkets typically offer a larger, more affordably priced selection of fresh produce when compared to local convenience stores.[139,140] This increases the likelihood that those living in ‘food deserts’ will purchase inexpensive nutrition-poor, calorie-dense, highly processed foods rather than fresh produce and high quality grains.[141] Improved access to supermarkets and farmer's markets and reduced access to high caloric foods and convenience stores has been associated with lower BMI and healthier diets among children. [137,138] However, the presence and proximity of healthier food options does not equate to utilization; residents must have the financial and health education resources to purchase the nutritious food options.[142]

Economic environment

The economic correlates of obesity include food prices, income and employment. The cost of fresh foods has increased whereas the price of energy-dense foods have fallen which many investigators have implicated in the rise in body weight.[143,144] Several studies show higher prevalence of high body mass index for children and adolescents with a higher cost for fruits and vegetables.[145] Those with more money and power tend to have greater access to resources which may include information, better food choices and opportunities for and access to safe physical activity options.[132] Although educational attainment has been on the increase, there have been some findings of increased obesity prevalence among children to mothers of low-education.[146] This may contribute to increased electronic media use and skipping breakfast among children.[147] Poor health outcomes such as obesity have been consistently linked with membership to lower social class. The overall poverty rate (15.1%) and childhood poverty rate (22.0%) have increased and the median household income has decreased ($49,445) indicating poorer economic conditions nationwide.[148] This social and economically disadvantaged health disparity may exist as a consequence of differential access to social goods and resources such as health care access, public transportation, and adequate housing.[149]

The social-class morbidity association may be explained by lifestyle, personal health behavior, access to health services, social and physical environment, and psychosocial factors. Lower income persons are more likely to engage in non-health promoting leisure activities rather than aerobic activity and higher fast food consumption when compared to more affluent populations. This effect of social class persists even after controlling for risk behaviors such as smoking and drinking. The association of lower social class and obesity in childhood may be bi-directional. The effects of poorer SES during childhood in creating an obesity-promoting environment may predict a similar social and physical environment into adulthood.[150]

At least 15% of the US population has no private or public health insurance with 9.8% of children being uninsured.[148] This population is more likely to be low-income, minority and have reduced access to health care. There is a higher prevalence of chronic disease including obesity among low-income populations which may substantiate a need for greater access to care.[151]

Physical environment

Decline in active transportation to school has paralleled the rise in childhood obesity. In 2001, only 13% of school-age children walk or bike to school compared to 42% in 1969.[152] Active, non-automobile transportation to school for children has been related to increased overall physical activity levels.[153] Increased likelihood to walk or bike to school was associated with higher perceived safety of neighborhood, presence of sidewalks, trails, bike paths and shorter distances to school from household.[154,155] Indicators of poor neighborhood quality such as non-continuous sidewalks, inadequate parks/recreation centers, poor street lighting, and high speed traffic are associated with less active residents.[156,157] The prevalence of excess weight increased for children residing in unsafe neighborhoods with the presence of garbage, vandalism/graffiti, and poorly kept/rundown housing.[48,115,158] Predictors of low quantities of built environment amenities were associated with an increased overweight and obesity prevalence among children, which include poor walkability, lack of parks/playgrounds, recreation centers and libraries.[115,158]

There is a higher *overweight including obesity* prevalence for children who were members of minority subgroups and living in neighborhoods under poor economic and built environment conditions.[158] Low-income and minority neighborhoods are disproportionately affected by property and violent crime which may decrease the overall perception of neighborhood safety and, consequently, the levels of outdoor physical activity especially among children.[159,160] Children living in poor quality neighborhoods are anywhere between 20-60% more likely to be overweight or obese than children residing in higher quality neighborhoods.[158] The risk of obesity is greatest for younger children and preteen girls living under poor neighborhood conditions.[158,161-163] Studies examining the association of parental perception of neighborhood safety and the risk of childhood obesity have been inconsistent.[55,164] However, several results indicate an increased risk of childhood obesity with poorer parental attitudes pertaining to neighborhood quality. There is some evidence suggesting that rural parents are more likely to perceive their neighborhood as safe compared to urban parents (80.3% vs. 70.9%).[108] The amount of television viewing time and time spent outside have been associated with maternal perception of the neighborhood; if the neighborhood is viewed as unsafe by mothers, children are more likely to spend time viewing television rather than playing outside.[165,166]

Culture and psychosocial environment

Factors that influence an individual's weight status include the sociology and psychology of food and weight in the US.[167] Cultural and environmental factors may promote and/or discourage health behaviors that act to increase the risk of obesity.[92] Parents influence a child's food environment both directly and indirectly through their own personal eating habits, controlling what and how much the child eats, and commenting on the child's dietary habits.[168,169] The child's culture and race-ethnic background should be considered because parents may have different opinions regarding appropriate child weight, diet and physical activity behaviors. Mexican boys are more likely to be obese if from affluent families with less authoritarian parents and are the only child or one of a few children.[170] A higher prevalence of obesity among boys living in Appalachia is associated with increased electronic media use and more high-fat, high-carbohydrate intake.[127] Intergenerational influence should be considered as well where in some cultures, the grandmother encourages higher weight among infants and children.[171,172]

Recent psychological studies have shown a positive association with family stress levels and obesity both in childhood and adulthood.[173,174] Many studies have shown how weight bias is experienced by overweight and obese individuals in health care, workplace, and education settings as well as in romantic and other social relationships.[175,176] One study has suggested that a person's risk for obesity increases if family members and/or friends (both same and opposite sex) were obese.[177] Another study has shown that overweight adolescents are more likely to have overweight friends compared to their normal weight counterparts.[178]

The American culture overwhelmingly delegates the pursuance of health as one's personal obligation. Therefore, it is not surprising to see that the popular media portrays obesity as a moral problem of sloth or gluttony.[179] This societal blame points at the individual for their lack of control, bad choices, and poor moral fiber which likely reinforces a negative stereotype based on body size.[180] Other studies have suggested that blaming the individual as a means to motivate them into weight loss may negatively impact both the individual's psychological and physical health.[181-183] An overweight or obese persons has a decreased chance of being hired or promoted and is more likely to receive lower wages than a normal weight peer.[184] Childhood obesity has been associated with poorer educational outcomes such as lower grade point averages and lower rates of college admission.[185-187]

Summary

These many social, economic, and political processes are at work differently throughout each state, which substantiates the need for identifying the county-level prevalence of overweight and obesity prevalence among US children. There is a public health need for further research into how the health of rural, urban and suburban populations differ from one another as well as identify potential demographic and socioeconomic disparities at the local level. A better understanding of the local-level burden of childhood obesity may help to identify geographic disparities as well as social and race-ethnicity subpopulations of greatest need.

State-specific childhood obesity and overweight prevalence has been previously illustrated in current literature[3]; however, knowledge of small-area, county-specific overweight and obesity prevalence estimates would promote a greater understanding of the burden of excess weight among U.S. children. We aim to predict county-level overweight and obesity prevalence among U.S. adolescents with Bayesian small area estimation using data from the 2003 and 2007 National Survey of Children's Health (NSCH).[2] Then, using these model-based estimates, we will explore the association of adolescent overweight and obesity prevalence with county-level sociodemographic and built environment correlates that may predict obesogenic conditions. This information has policy implications at the local, state and national level. Identifying spatial patterns of obesity can help focus attention on place-based characteristics associated with better health.

CHAPTER 2.1: Small area Bayesian model-based estimation of overweight and obesity prevalence among US adolescents (10-17 years) by county

INTRODUCTION

Childhood obesity continues to be a growing public health concern with 12.5 million (17%) school-age children and teens affected.[1] Rates of obesity among children have begun to plateau after nearly tripling since the 1960s.[1] Even though the rates of newly obese (body mass index over the 95th percentile) may be leveling off; the most obese are becoming heavier.[1] Obesity has a negative impact on an individual's health in childhood as well as into adulthood, and economically on the nation's health care system. A high risk of adverse health outcomes is associated with childhood obesity where 70% of obese children have at least one additional cardiovascular risk factor, and 30% have two or more.[7] Even if obese children lose weight prior to adulthood, they remain at a higher risk for chronic disease throughout life.[9] The prevalence of obese adults is double that observed in children. If current trends continue, 75% of adults will be overweight or obese by 2015 with projections among children to nearly double by 2030.[36] The care associated with obesity results in a high economic burden to families and society.

Overweight and obese children are more likely to be non-Hispanic Black or Hispanic than non-Hispanic White. [1,54-57] An obese child is more likely to be living in a household that is low-income, low-education, single mother and with an obese parent. The prevalence of overweight and obese children is higher in rural areas and in the Southeastern region of the US. Obese children are more likely to be from low-income households with greater disparities among certain race-ethnicity and sex subpopulations.[1,21,47]

State-specific childhood obesity and overweight prevalence has been previously illustrated[3]; however, knowledge of small-area, county-specific overweight and obesity prevalence estimates would promote a greater understanding of the burden of excess weight among U.S. children. Identifying spatial patterns of obesity can help focus attention on place-based characteristics associated with better health. There is a need to identify demographic and socioeconomic disparities at the local level. These results may identify the racial, economic, regional and urban/rural differences in the burden of the childhood overweight and obesity prevalence by county which has policy implications at the local, state and national level.

CDC has published a county-level map of the obesity prevalence among US preschoolers in low-income families yet these data are limited to 2-4 year olds receiving Women, Infants and Children (WIC) program assistance and does not include all US counties.[188] County-level estimates for overweight and obesity prevalence among U.S. adolescents have not been previously published at the national level. It can be problematic to directly estimate county-level prevalence without the costly sampling of sufficient observations in every county. In typical state- and nationally-representative surveys, data of smaller geographic units, such as at the county-level compared to the state-level, are subject to reduced sample size and thus increased statistical variances for the resulting estimate.[189] Conventional epidemiologic frequentist analyses, such as unconditional and conditional regression, of sparse data often result in statistically unstable estimates.[190,191] There are several methodological approaches in practice to produce small area estimates for data obtained with a complex survey design. As outlined by Ghosh and Rao, there are several limitations associated with two of the earlier approaches, demographic methods and synthetic estimators.[192] We chose to use a more recently developed full Bayesian model based on Markov chain Monte Carlo (MCMC) approach to estimate the prevalence of childhood obesity (and overweight) in all 3,141 counties using a hierarchical Poisson regression model for local-, state- and age/race/sex-specific prevalence rates. This modeling approach pools information across subgroups defined by demographic and geographic domains. It will build indirect estimates for counties with missing data and realistic predictions for counties with sparse data. The small area estimation is an approach that has been explained in detail in previous literature but we will briefly describe it here.[2,193,194]

The use of Bayesian methods has recently become more popular due to the development of MCMC algorithms and improved computational resources. Both Bayesian and frequentist approaches incorporate the likelihood, yet the Bayes theorem differs by combining the observed likelihood data with a prior probability to construct a posterior predictive distribution. The prior probability distribution informs the posterior distribution but as the sample size increases, the Bayesian estimates are influenced more by the observed data and less by the prior probability data. The MCMC approach iteratively samples from the joint posterior distribution after a period of convergence. This joint posterior distribution is then summarized with the posterior mean and 95% credible intervals which are functionally similar to maximum likelihood point estimate and 95% confidence intervals.[195]

The ability to predict parameter values for geographic units with few or no observed data is an advantage of Bayesian smoothing, and is akin to a missing data problem.[190] Small area estimation can improve on prevalence estimates by combining observed data with state-specific means, but also by incorporating spatial proximity information acknowledging that places close to one another on average tend to be more similar than places far from one another. The Bayesian model borrows statistical strength from both population and state-level means, as well as from the prevalence patterns in neighboring counties making the predicted prevalence the integration of multiple sources of information. The model-predicted race-, sex-, and age-specific prevalence for each county is then post-stratified to county-specific population structure (denominators) using demographic data to estimate a single, unique county-specific overweight and obesity prevalence. Neighboring counties were identified as those that shared a boundary with the index county. This statistical approach stabilizes the rate estimate for a county with sparse data while preserving geographic resolution.[196,197]

The primary objective of this study is to identify geographic disparities of the prevalence of overweight and obesity among U.S. adolescents at the county level. The geographic pattern of overweight and obesity prevalence among U.S. children may be similar to the spatial distribution of adult obesity by county. Studies have revealed a non-uniform prevalence of adult obesity at the county, state, and national level. In this study, we aim to estimate overweight and obesity prevalence by county among U.S. adolescents with the Bayesian small area estimation approach using 2003 and 2007 National Survey of Children's Health (NSCH) data.[198,199] These estimates have been previously unavailable due to the combination of restricted access to NSCH data containing county identifiers and the sophisticated spatial modeling approach required to determine the predicted prevalence estimates. These model-based estimates will estimate the county-level prevalence of overweight, obesity, and overweight including obesity for U.S. adolescents accounting for the local age, sex, and race population structure.

METHODS

Data Sources

The NSCH is administered by the Centers for Disease Control and Prevention's (CDC) National Center for Health Statistics (NCHS) under the direction and funded by Maternal and Child Health Bureau (MCHB) of the Health Resources and Services Administration (HRSA). The 2003 NSCH was conducted between January 2003 and July 2004.[200] The 2007 NSCH was conducted between April 2007 and July 2008.[201] These surveys used the State and Local Area Integrated Telephone Survey (SLAITS) program to collect physical and psychological health information for children from ages 0 to 17 years. Random-digit dial sampling selected households with children under the age of 18 years for all 50 states and the District of Columbia (and Puerto Rico which were excluded for this study). Only one child was selected from each eligible household. The survey respondent was identified as the parent or guardian who was most informed on the selected child's health history including the parent's or guardian's report of the child's height and weight.[200] There was an average sample of 1,800 children per state for each year of the survey. Interviews were conducted in English, Spanish and several Asian languages.

The sampling survey allows for design-based estimates of health parameters to make inferences about states; however, this sampling approach may yield few or no sampled children in some counties within states.[192]

The combined years of NSCH data required for this study is restricted at the county-level for confidentiality reasons. The geographic identifiers (county-state Federal Information Processing Standard [FIPS] code) are only available through the Research Data Center (RDC) at CDC. Following project approval and per our RDC user agreement, analyses of these confidential data were allowed only on-site and approved output was allowed to leave when it no longer posed a disclosure risk.[202]

The 2010 US Census Bureau TigerLine shapefiles for US state and counties were used to construct choropleth maps of the model-based prevalence estimates for each overweight and obesity outcome.

Data validity issues surround BMI measurement data for young children (less then 10 years of age) when comparing small geographic units (county) or population (race, sex) subgroups.[114,200,201,203] Height and weight information collected from parents and/or guardians via telephone has been shown to be biased for children less than 10 years of age as a result of height underestimation providing an exaggerated BMI.[204,205] As a result, the data for this study was limited to county-level BMI information for children aged 10 to 17 years.

Variable Descriptions

The target parameter is the model-based estimate of county-specific *overweight alone*, *obesity alone*, and *overweight including obesity* prevalence for US adolescents (10-17 years old). Determination of *overweight*, *obesity* and *overweight including obesity* among surveyed children was calculated using the NSCH variable that categorizes BMI-for-age and-sex for each selected child. This variable identified children as underweight, normal weight, overweight or obese as defined by CDC’s BMI-for-age and-sex growth charts where underweight is lower than the 5th

percentile, overweight is at least the 85^{th} percentile but less than the 95^{th} percentile, and obese is at or above the 95^{th} percentile.[65]

The selected child's county was the primary covariate of interest. In addition to county of residence, we also used individual-level demographic variables obtained from NSCH and county-level population estimates from the 2005-2009 (5-year estimate) US Census American Community Survey (ACS). The NSCH variables included the selected child's age (categorized as 10-14 or 15-17 years), race (non-Hispanic White or other), sex (male or female), and NSCH survey year (2003 or 2007). A county-level analysis using NSCH data did not allow for a finer race-ethnicity classification. All variables were reported by the selected child's respondent (parent or guardian) following NSCH protocols.[200,201]

Overweight and obesity prevalence estimator

Due to sample size, this pooled cross-sectional analysis will combine both the 2003 and 2007 NSCH data and include the survey year as an indicator variable within the model. For each US county, the individuals can be aggregated by sex (male/female), race (non-Hispanic white/other), age (10-14/15-17), and survey year (2003/2007). Following Cadwell, et al[2], the (unobserved) prevalence of adolescent obesity in each county, *i*, is:

$$p_i = \frac{\sum_{j=1}^{16} Y_{ij}}{\sum_{j=1}^{16} N_{ij}}$$

The cross-classification of age, race, sex and survey year resulted in 16 stratum (*j*) per county where i=1,…3141 (number of counties), j=1,…16 (number of age, race, sex, survey year classes), Y_{ij} is the number of adolescents overweight or obese in county *i* and stratum *j*, and N_{ij} is the total population in that county and stratum. Because Y_{ij} is not observed (only some or perhaps none of the overweight or obese adolescents in a given county and stratum were sampled by NSCH), we estimate this parameter using information from sampled NSCH respondents, as well as spatial and group mean information.

Small Area Estimation

We extended Cadwell, et al's[2] approach by estimating the incompletely observed county and stratum-specific overweight or obesity count with a conditional autoregressive (CAR) Bayesian spatial model.[206] The Bayesian hierarchical Poisson regression model was implemented via MCMC separately for each Census-based region (Northeast, South, Midwest and West) and division (New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific) because the spatial proximity matrix for the entire country was too computationally burdensome to do in a single run. Our proposed model includes state-specific random intercept and state-specific sex, race, age and survey year parameters and takes into account both spatially structured and unstructured random county effects.

$$y_{ij} \sim Poisson(\lambda_{ij})$$

$$\log(\lambda_{ij}) = \alpha_{state} + \beta_{state,j} * X_{ij} + S_i + U_i + \log(n_{ij})$$

$$\beta_{state,j} \sim N(0, \sigma^2_{state,j})$$

$$S_i \sim CAR(1, \sigma^2_s)$$

$$U_i \sim N(0, \sigma^2_u)$$

$$1/\sigma^2 \sim Gamma(.5, .005)$$

In this model, y_{ij} represents the observed count of overweight and obese adolescents sampled in NSCH within county *i* and demographic stratum *j* and is distributed Poisson with parameter λ_{ij}. The relative county and stratum estimator, λ_{ij}, is a function of a state-specific random intercept, α, the effects for age, race, sex, and year (β's), the spatially-structured random county effect S_i and the unstructured random effect for county, U_i. The log of the number of NSCH sampled households in each county and stratum is included as an offset. In a Bayesian setup, parameters of interest are considered random variables arising from prior distributions.

The state intercept has a flat, non-informative prior. Each of the stratum-specific β's arise from a state-specific normal distribution with mean zero and variance σ^2. The spatially structured random term follows a CAR distribution, and the unstructured random term U follows a normal distribution. The inverse of each variance term (the precision) is distributed Gamma.

A strength of the Bayesian model is in its ability to pool statistical strength across the observed data, state-varying beta coefficients, and from spatially neighboring counties in the form of spatial random effects. The random state effect was included to allow counties within state to be more similar compared to those across state boundaries. The county-level random effects use a standard conditionally autoregressive (CAR) prior distribution to smooth the county-level prevalence estimate by borrowing information from proximate neighbors, accounting for the possible similarity of adjacent counties. The resulting stratum- and county-specific risk are post-stratified to the county's population by age, race, and sex, producing a single summary estimate of the county-specific overweight and obesity prevalence. The model-based (predicted) mean prevalence from the posterior distribution was produced for each county including those without observed NSCH sample data. Bayesian credible intervals (sometimes referred to as 'confidence intervals') were defined as the 2.5^{th} and 97.5^{th} percentile of the posterior distribution. The MCMC technique was employed with two chains for 20,000 iterations, and chain convergence was assessed. All Bayesian estimation was conducted using R Project Statistical Software and WinBUGS.[207]

These model-based county-level prevalence estimates for adolescent *Overweight including obesity*, *Overweight alone,* and *Obesity alone* were summarized in choropleth maps for the nation using ArcGIS software (ESRI, Redlands, CA) and state and county TigerLine shapefiles of the United States.[208] We compare each county's predicted prevalence rate estimate to the expected national rate using the 2003 and 2007 NSCH design-based mean for each outcome. The rationale for choosing the national average as the reference is to identify the geographic areas of least and highest burden for overweight and obesity prevalence among U.S.

children. A county is categorized as high (and low) *overweight alone*, *obesity alone* or *overweight including obesity* burden if the county's model-based estimate is above (and below) the national mean or in the highest (and lowest) decile of the mean. A county was identified as being above (or below) the national mean if the 2.5th (97.5th) percentile of the posterior distribution was greater than (less than) the national mean. Bayesian modeling has the ability to approximate the probability that a county is really higher (or lower) than that national average, and therefore these extremely high or low counties are likely to be truly different from average. Many counties' mean estimate might be higher (or lower) than the mean, but if the 95% CI includes the mean it may not be significantly different.

Sensitivity Analyses

The posterior predicted (model-based) distribution estimates were compared with the observed (design-based) estimates to explore the predictive properties of the Bayesian model. This model vs. design-based comparison was performed overall for each outcome (overweight alone, obesity alone and overweight including obesity) for all counties, counties with at least 50 respondents and counties with at least 100 respondents. To assess sensitivity to choice of data process partitioning (running models separately in four census regions as compared to separately in 9 census division), the model-based prevalence estimates for US Census-derived divisions were compared to the estimates by US Census-derived region for all three outcomes.

RESULTS

Study Sample

There were a total of 48,742 and 45,897 children aged 10 to 17 years examined in the 2003 and 2007 NSCH surveys, respectively. Approximately 4% of observations had missing BMI data for each sampled year. Data with missing or invalid geographic identifiers (county-state FIPS code) were also excluded from the analyses. An invalid county-state FIPS code was defined as a county-state FIPS code that was not present in both the combined NSCH data and the 2010 US Census TigerLine shapefile for US counties. The 2007 data did not have any observations missing or containing invalid county-level identifiers, but 6.2% (n=2909) of the 2003 data were missing or contained invalid county-level identifiers. The final study sample for analysis was 45,833 and 44,101 children aged 10-17 years in 2003 and 2007, respectively, for a final two-year combined NSCH data set of 88,934 observations. The 2003 NSCH sampled households residing in 2,818 distinct counties and the 2007 NSCH sampled households in 2,333 counties. The combined NSCH data set used in this modeling approach utilizes design-based estimates for 2,925 US counties (Table 1).

Mean model-based prevalence estimates

The mean model-based prevalence estimate of *Overweight including obesity* among U.S. adolescents by county was 30.7% (4.7%-57%, SD=4.8). The *Overweight alone* prevalence is 15.8% (1.9%-39.4%, SD=2.1%) and the *Obesity alone* prevalence is 15.2% (1.4%-36.7%, SD=3.8%) [Table 2]. The prevalence of *Overweight including obesity* and *Obesity alone* is highest in the Mississippi Delta region, the Appalachian counties of Tennessee, Kentucky, and West Virginia, the coastal regions of North and South Carolina, tribal lands in the western United States, along the Texan-Mexican border, and northwestern Alaska. (Figures 1 and 3) The South region and East South Central division have the highest prevalence for all three outcomes (Table 2). The geographic disparities of *Overweight alone* prevalence is less apparent than when obesity is included yet Alabama and Alaska have a high proportion of counties with high *Overweight alone* prevalence (Figure 2).

Above and below national mean

The choropleth maps of prevalence estimates for counties significantly below and above the national mean (where the posterior mean and 95% credible interval excludes the national mean) are seen in Figures 4-6. There were 177 and 123 counties below and above, respectively, the national *Overweight including obesity* prevalence mean of 31.10% (30.41-31.79%). Counties with an *Overweight including obesity* mean prevalence (22.27% [8.38-26.28%]) below the national mean are located primarily in the West especially Wyoming, Utah, Colorado and North Dakota (Figure 4). Those counties with an *Overweight including obesity* prevalence (41.94% [35.20-60.27%]) above the national mean are primarily in Mississippi with some rural counties in Alabama, South Carolina, and Kentucky (Figure 4).

There were 18 and 27 counties below and above, respectively, the national *Overweight alone* prevalence mean (15.49% [14.97-16.02%]). Counties with an *Overweight alone* prevalence (8.72% [1.92-13.12%]) below the national mean are located primarily in Wyoming (Figure 5). Those counties with an *Overweight alone* prevalence (23.58% [18.59-39.42%]) above the national mean are located primarily in Mississippi and rural South Carolina (Figure 5).

There were 356 and 36 counties below and above, respectively, the national *Obesity alone* prevalence mean of 15.61% (15.05-16.17%). Counties with an *Obesity alone* prevalence (10.08% [1.39-13.40%]) below the national mean are located primarily in West, a few New England states and southern Alaska (Figure 6). Those counties with an *Obesity alone* prevalence (26.07% [19.65-36.73%]) above the national mean are observed in some rural areas of Mississippi and Alabama (Figure 6).

Lowest/Highest Decile of the Mean

Counties in the lowest and highest decile of the mean present a slightly different geographic pattern of the *Overweight including obesity* prevalence among US adolescents (Figure 7). The Mountain and West North Central Census divisions are home to the lowest *Overweight alone* and *Obesity alone* prevalence counties (Figure 8). The Mississippi Delta region and rural Alaska have some of the highest *Overweight alone* prevalence (Figure 9).

The variability between the model-based and design-based estimates decreased for US counties with larger sample sizes. There was little change in variability when analyzing counties beyond 50+ respondents. The independent Census region and division models also agreed with the exception of only a few extreme outliers. After accounting for counties with sparse data, the predicted and observed estimates mostly agreed for all three outcomes (Figures 10-12).

DISCUSSION

These results estimate the county-level prevalence of overweight and obesity among US children aged 10-17 years using a Bayesian small area estimation based on the MCMC approach. This technique borrows statistical strength from spatially-proximate neighbors, and from adjustment for the relations between age, sex, and race in the local county population on the overall county prevalence. Since we were estimating prevalence at the county-level, we chose to combine the NSCH data for 2003 and 2007 to increase precision.

The geographic pattern of *Overweight including obesity* among US adolescents is quite similar to that seen among adults with higher prevalence in the Mississippi Delta region, the Appalachian counties of Tennessee, Kentucky, and West Virginia, the coastal regions of North and South Carolina and tribal lands in the western United States.[209] Additionally, counties along the Texan-Mexican border and northwestern Alaska showed a higher *Overweight including obesity* prevalence.

A major strength of this study is the ability to predict small area estimates that are not otherwise available. No national research to date has been published to examine this geographic pattern for excess weight among this age group at the county level. These model-based prevalence estimates elucidate the intra-state differences of adolescent overweight and obesity prevalence among US counties. The flexibility of the Bayesian MCMC modeling approach allows it to be applied to complex data sets that include spatial correlation. Our study results are further strengthened by the fact that the combined two-year NSCH sample is moderately large in size, which may lend to the generalizability of our findings to the US adolescent population. The Bayesian modeling approach is advantageous in many ways including the ability to confidently predict counties that are above the national mean. These counties may identify areas of a higher burden such as Mississippi and rural areas of other southern states more accurately than looking at counties with estimates in the highest decile. As suggested in the literature, counties in the West especially Wyoming, Utah and Colorado had lower estimates of overweight and obesity prevalence which may indicate successful intervention programs and/or unique low obesity burden demographic profiles.

A potential limitation of this study includes possible outcome misclassification due to the subjective nature of height and weight measurements from the selected child's parent or guardian. It was not possible to include the prevalence for every county since less than 7% (216) had no NSCH respondents and many had sparse data (only 200 counties with more than 100 respondents). This analysis was limited to a two-category race-ethnicity groups due to the small NSCH sample size by county which only allows for a comparison between non-Hispanic White to all other races. The lack of additional high body mass index predictors at the individual-level such as home and school dietary patterns (number of meals eaten at home and school), parental characteristics (physical activity levels and BMI), and measures of food access (number of convenience and fast food stores vs. grocery stores, supermarkets and farmer's markets) lend to the inability to further evaluate variation in possible determinants of overweight and obesity among US adolescents. Further, this study is limited by its cross-sectional design and restriction to children older than 10 since the parent-reported height and weight measurements are less reliable for younger children.[203,204]

An implication of this study is to identify geographic disparities and unique risk profiles of adolescent overweight and obesity prevalence at the county-level. The estimates provided from this model-based approach are likely to be useful at the local-, state-, and national-level by policymakers and public health agencies. Since most public health programs are implemented at the local-level, these results may aid in identifying areas of greatest burden. Counties with a lower burden of excess weight among adolescents may serve as a marker of positive environments. Whereas, counties with a high prevalence of overweight and obesity among US children could possibly be a target for additional public health intervention. A temporal analysis may identify counties with successful intervention by determining which counties have reducing prevalence estimates from 2003 to 2007. Future research that would contribute to this topic would include a multi-level approach to examine predictors at the individual and county level. Further, it may helpful to examine how much variance is not explained by the model proposed by mapping the residuals per county to determine if there is a spatial pattern to the model error.

CHAPTER 2.2: Built and social environmental correlates of county-level (small area) overweight and obesity prevalence among US adolescents

INTRODUCTION

Childhood obesity continues to be a growing public health concern with 12.5 million (17%) school-age children and teens affected.[1] Rates of obesity among children have begun to plateau after nearly tripling since the 1960s.[1] Even though the rates of newly obese (body mass index over the 95th percentile) may be leveling off; the most obese are becoming heavier.[1] Obesity has a negative impact on an individual's health in childhood as well as into adulthood, and economically on the nation's health care system. A high risk of adverse health outcomes is associated with childhood obesity where 70% of obese children have at least one additional cardiovascular risk factor, and 30% have two or more.[7] Even if obese children lose weight prior to adulthood, they remain at a higher risk for chronic disease throughout life.[9] The prevalence of obese adults doubles that observed in children. If current trends continue, over 40% of adults will be obese by 2015 with projections among children to nearly double by 2030.[36] The care associated with obesity results in a high economic burden to families and society.

Overweight and obese children are more likely to be non-Hispanic Black or Hispanic than non-Hispanic White. [1,54-57] An obese child is more likely to be living in a household that is low-income, low-education, single mother and with an obese parent. The prevalence of overweight and obese children is higher in rural areas and in the Southeastern region of the US. Obese children are more likely to be from low-income households with greater disparities among certain race-ethnicity and sex subpopulations.[1,21,47]

The two strongest predictors of childhood obesity, physical inactivity and poor nutrition, have been consistently linked to the built environment which influences available opportunities for physical exercise and access to food.[88] Predictors of physical inactivity include high electronic media use (television watching, video game playing, and computer activities), older age (15-17 years), female gender, and inactive parents.[107,108] Increased physical activity levels among adolescents is positively associated with maternal age, parental income status and living in a higher socioeconomic neighborhood.[112,113]

State-specific childhood obesity and overweight prevalence has been previously illustrated in current literature[3]; however, knowledge of small-area, county-specific overweight and obesity prevalence estimates would promote a greater understanding of the burden of excess weight among U.S. children. Identifying spatial patterns of obesity can help focus attention on place-based characteristics associated with better health. There is a need to identify demographic and socioeconomic disparities with a national scope but a local scale. These results may identify the racial, economic, regional and urban/rural differences in the burden of the childhood obesity prevalence by county. This information has policy implications at the local, state and national level. In this study, the associations between childhood obesity and the characteristics that may predict obesogenic environments are examined. Currently, it is not known what structural barriers correlate with the nationwide county-level overweight and obesity prevalence among US children. Nor is it well known whether the degree to which the racial and age composition contribute to the observed differences.

The primary purpose of this study is to identify social, food, and physical environmental characteristics that may correlate with an unbalanced burden of overweight and obesity prevalence among adolescents in US counties. We used Bayesian spatial model-based estimates for overweight and obesity prevalence among US children aged 10 to 17 years using 2003 and 2007 National Survey of Children's Health (NSCH) data that were obtained in Chapter 2.1. We performed a hypothesis-generating analysis of prevalent adolescent overweight and obesity at the county level with county-level contextual variables that may predict obesogenic environments.

METHODS

Data Sources

The county-level Bayesian model-predicted prevalence estimates for US adolescents (10-17 years) constructed from 2003 and 2007 NSCH data is used for this study. The combined years of NSCH data required for this study is restricted at the county-level. The geographic identifiers (county-state FIPS code) are only available through the Research Data Center (RDC) at CDC. Following project approval and per our RDC user agreement, analyses of these confidential data were allowed only on-site and approved output was allowed to leave when it no longer posed a disclosure risk.[202] This small area estimation approach is explained in Chapter 2.1 of this thesis.

The 2010 US Census Bureau TigerLine shapefile for counties was used to approximate the 2005 total population and population density estimates.[208] The data for 2000 and 2010 were collected from the database file associated with the shapefile and averaged in SAS statistical software to be used in regression models.

Variable Description

The dependent variable of this study in determining the ecologic correlates of obesity is the county-level model-based overweight and obesity prevalence estimates among US adolescents (10-17 year olds) using the 2003 and 2007 NSCH data constructed in Chapter 2.1.

We considered county-level contextual variables in several domains: socioeconomic, food environment, neighborhood quality and built environment. All public-use data were merged with the model-based prevalence estimates by state-county FIPS code. The dependent (overweight and obesity prevalence) and independent (contextual) variables were evaluated and determined to meet distribution assumptions.

The socioeconomic status (SES) of the county was estimated with poverty and income measurements. The child poverty rate (proportion of the population 18 years or younger that is living below the poverty threshold), Gini coefficient (proxy for income inequality), and median household income variables were obtained from US Census Bureau, 2005 Small Area Income and Poverty Estimates (SAIPE).[210] The unemployment rate used is the annual estimate (2005) provided by the Bureau of Labor Statistics (BLS).[211]

Food access within the county was approximated with measurements of food environment and food assistance variables. The presence and density of limited (fast food) and full service restaurants, grocery stores, farmers markets, and convenience stores (with and without gas) per county population were measured by US Census Bureau County Business Patterns (2008) and accessed via USDA Food Environment Atlas.[212] Proximity to a food store by availability of vehicular transport (car or no car) and low-income status were obtained from a 2006 Report to Congress: Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences (accessed via USDA Environment Atlas).[213] Food assistance variables include participation in food assistance programs (i.e. WIC and SNAP) and reduced- and free-lunch eligibility for school-aged children which were obtained from U.S. Census Bureau, Current Population Statistics 2009: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service (accessed via USDA Environment Atlas).[214]

Neighborhood safety was approximated by violent crime rate data obtained from Uniform Crime Reporting Program Data (2003, 2005 and 2007): County-level Detailed Arrest and Offense Data (accessed via Interdisciplinary Consortium of Social and Political Research).[215] Built environment variables include rurality (2006 NCHS Urban/Rural Classification Scheme for Counties), proportion of workers whose primary means of transportation is walking (U.S. Census Bureau, 2005-2009 American Community Survey-5 year estimate) and presence of recreation/fitness centers (U.S. Census Bureau, 2008 County Business Patterns).[212,216,217] The data collection required for this study was declared exempt by the Emory Institutional Review Board (see Appendix).

Study design

First, distribution assumptions, correlation and collinearity were evaluated for all dependent and independent variables (see Appendix). Next, choropleth maps of county-level prevalence for adolescent *Overweight including obesity*, *Overweight alone*, and *Obesity alone* were constructed for the nation in ArcGIS software (ESRI, Redlands, CA) using state and county TIGER/Line shapefiles of the United States (Figure 1-3).[208]

This pooled cross-sectional analysis used county-level model-based estimates for overweight and obesity prevalence among US adolescents (10-17 years) as constructed in Chapter 2.1 of this thesis. The covariates were regressed with all three overweight/obesity outcomes as continuous, dichotomized at the national mean, standardized and in quintiles with the exception of rural/urban status which was categorized as rural, suburban, or urban, Census-based region and the estimates for normal and log transformed total population and population density for 2005. Multivariable linear regression analyses were conducted to test the associations of the county-level contextual variables with overweight and obesity prevalence. A count model was estimated for all three outcomes. Poisson regression was attempted first and the deviance goodness of fit statistic for over-dispersion was estimated. A likelihood ratio test confirmed the use of a negative binomial model, which does not have the assumption of mean count being equal to its variance, as is the case in the Poisson model. Model fit was determined for all models for each outcome with all variable classifications (continuous, dichotomized at the national mean, standardized and in quintiles) were considered. Due to overdispersion of the count data and the preference to put the contextual variables on a comparable scale, we proposed a negative binomial model with standardized covariates (excluding rurality, Census-based region and population density) for each outcome adjusting for county-level contextual characteristics. The regression models were assessed for goodness of fit using SAS 9.3 (SAS Institute, Inc. Cary, NC) to examine the association of the model-based *Overweight including obesity*, *Overweight alone*, and *Obesity alone* outcomes with county-level contextual variables while considering geography (rurality and

Census-based region) and population (normal and log transformed total population and population density) [Table 4]. These variables attempt to serve as proxy measurements for the social, physical, food and built environments at a local level. A county was categorized as high (and low) overweight and/or obesity burden if the county's model-based estimate is above (and below) the national mean. A county was identified as being above or below the national mean if its posterior mean and 95% credible interval excluded the national average for the respective high body mass index prevalence estimate. A .05 level of significance was used in these analyses.

RESULTS

Basic description of US counties

A summary of basic descriptive statistics is seen in Table 3. Less than 4% of workers state that walking is their primary means of transportation. Nearly a quarter (23.6%) of low-income households live more than 1 mile from a food store yet only 5.6% are greater than 10 miles. Only 4% of households with no car are more than 1 mile to a food store and less than 1% of households with no car are further than 10 miles to the nearest store. There are more convenience stores with gas when compared to those with no gas per 1,000 county residents, 0.55 vs. 0.07, respectively. The number of fast food (limited service) restaurants (0.81 per 1,000 county residents) just outnumbers the number of full-service restaurants (0.59 per 1,000 county residents).

The food environment also varies by food assistance program type. There are more SNAP-authorized stores (0.88 per 1,000 county residents) over WIC-authorized stores (0.25 per 1,000 county residents) and the average monthly SNAP benefits per recipients is $89.01. Almost one-third (31.4%) of a county's low-income population are receiving SNAP assistance. The near majority (47.2%) of school-aged children are eligible for free or reduced-cost lunch.

Obesity and diabetes burden an average of 28.9% and 9.91%, respectively, of the adult population. In 2005, the median household income is $39,158 with an unemployment rate just under 5.5%. On average, non-Hispanic black and Hispanic comprise less than 20% of a county's population, 8.79% and 7.53%, respectively. About 43% of US counties are rural.

Contextual differences above and below the national mean

For counties with an excess weight prevalence below the national mean, income inequality and violent crime rate did not vary considerably for all outcomes. As might be expected, lower overweight and obesity prevalence was associated with increased walking to work, higher median household income, lower unemployment rates, lower childhood poverty rates, lower proportions of school assistance eligible children and lower rates of indicators of poor adult health (both obesity and diabetes), lower proportions of low-income and non-vehicular households more than 1 mile to a food stores and lower proportion of low-income households receiving SNAP assistance. Alternatively, increased proportions of low-income and non-vehicular households over 10 miles to a store were associated with lower childhood obesity prevalence. The number of convenience stores with gas per county population increased only with *overweight alone* prevalence. Higher fast food establishments per county population was observed for low burden counties across all excess weight outcomes. There is a lower percentage of minority subgroups in counties with lower overweight and obesity prevalence when compared to the national mean. For counties with *overweight alone* prevalence below the national mean, the total WIC and SNAP redemptions are doubled that of the national average. The proportion of rural *overweight alone* prevalence counties below the national mean was less than the national mean (Table 4).

Most indicators worsen or show no great change with above average overweight and obesity prevalence suggesting poor food assistance, reduced food access, poor socioeconomic conditions and built environment. There is a disproportionate increase in the proportion of non-Hispanic black county population when compared to the national average. The percentage of school-aged children eligible for school food assistance is nearly doubled for counties with high excess weight prevalence. Yet a decreasing number of fast food restaurants per county population and percentage of low-income households more than 1 mile from a food store was associated with higher overweight and obesity prevalence. A high burden county's rurality status had an interesting presentation. The prevalence of excess weight among adolescents appears to change as a function of rurality where high burden counties tend to be less rural for both overweight and obesity prevalence when compared to the national average. The high *obesity alone* prevalence counties account for the bulk of total food assistance (both WIC and SNAP benefits), nearly 6 times the national average (Table 5).

Regression analysis: Overweight including obesity

In final fully adjusted negative binomial models, children were more likely to be overweight or obese in counties with high violent crime rates, high proportion of non-vehicular households greater than 1 mile from a food store, higher monthly SNAP allowances, higher proportion of low-income population receiving SNAP assistance, high percentage of school-aged children receiving free and reduced-cost school lunch, and high adult diabetes and obesity rates. High childhood *overweight including obesity* prevalence counties were also associated with poor socioeconomic environments characterized by high child poverty and high unemployment rates. The racial composition also impacted the association where high prevalence was seen; in counties with high proportion of black and Hispanic populations. Urban and suburban counties had higher *overweight including obesity* prevalence when compared to rural counties. The South was positively associated (more than the Northeast and Midwest) with higher *overweight including obesity* prevalence when compared to the West. Conversely, higher numbers of workers who walk to work and increased household income were associated with increased *overweight including obesity* prevalence. The number of convenience stores with no gas and WIC redemptions per county population were inversely associated with *overweight including obesity* prevalence (Table 7).

Regression analysis: Overweight alone

In the final fully adjusted negative binomial model for *overweight alone* prevalence as the outcome, some similarities and dissimilarities exist when compared to the model with *Overweight including obesity*. It remained likely for adolescents to be *overweight alone* in counties with high violent crime rates, high WIC allowances per county population, high adult diabetes and obesity rates, high median household income, high unemployment rates and high proportion of workers who walk to work as was also observed in the combined outcome model. Demographics may be less associated when compared to both outcomes combined because an increased risk for *overweight alone* was suggested in counties with a high proportion of Hispanic populations but not with a high proportion of Black populations.

Many dissimilarities exist for variables representing all domains when examining the prevalence of *Overweight alone* among adolescents. The percentage of non-vehicular households more than 1 mile to a food store, number of convenience stores without gas services, average monthly SNAP benefits, percentage of low-income households receiving SNAP assistance, proportion of school-aged children eligible for school food assistance, child poverty rate, and geography (rurality or Census-based region) no longer appear to be associated with the outcome. A unique profile of the built and food environment appears in the *Overweight alone* model. An increasing number of recreation centers and grocery stores per county population were associated with high *overweight alone* prevalence. Convenience stores with gas and full-service restaurants per county population were negatively associated with *overweight alone* prevalence. High *overweight alone* prevalence was associated with high total county food assistance for both WIC and SNAP (Table 8).

Regression analysis: Obesity alone

The final fully adjusted negative binomial model for the outcome of *Obesity alone* prevalence had more similarities and fewer dissimilarities with the combined outcome model when compared to the *Overweight alone* model. Adolescents were more likely to be obese in counties with a high proportion of non-vehicular households greater than 1 mile from a food store, higher monthly SNAP allowances, higher proportion of low-income population receiving SNAP assistance, increased percentage of children receiving free and reduced-cost school lunch, and high adult diabetes and obesity rates as was observed in the combined outcome model. Similarly, high childhood *obesity alone* prevalence counties were also associated with poor socioeconomic environments characterized by high child poverty and unemployment rates. The racial composition also impacted the association where high *obesity alone* prevalence was seen in counties with higher proportion of black and Hispanic populations. Urban and suburban counties had higher *obesity alone* prevalence when compared to rural counties. The South was positively associated (more than the Northeast and Midwest) with higher *obesity alone* prevalence when compared to the West. Increasing median household income was positively associated with higher *obesity alone* prevalence. The number of convenience stores with no gas per county population was inversely associated with *obesity alone* prevalence.

Some dissimilarities existed between the combined outcome model and the *obesity alone* model. The proportion of workers who walk to work, violent crime rate, WIC allowance per county population, and population density no longer appear to be associated with the outcome of *obesity alone* prevalence. The proportion of non-vehicular households greater than 10 miles from a food stores were inversely associated with *obesity alone* prevalence. A positive association is suggested between income inequality and *obesity alone* prevalence (Table 9). In contrast to the *overweight alone* model, the number of recreation centers per county population is negatively associated with *obesity alone* prevalence among adolescents.

DISCUSSION

There is a concordance of adolescent overweight and obesity with certain indicators of poor socioeconomic environment such as high child poverty rate and unemployment rates. Home and school food assistance was observed to be positively associated with a higher *overweight including obesity* prevalence. An increased risk of childhood overweight and obesity among counties with high proportions of black and Hispanic population may suggest residential segregation effects. Yet differences arise when *overweight alone* prevalence and *obesity alone* prevalence were assessed separately. Poor adult health, high unemployment rates and Hispanic residential segregation were associated with higher *overweight including obese* prevalence. Counties with a higher *obesity alone* prevalence were associated with increased food assistance and poor socioeconomic indicators as well as more defined geographic patterns such as high *obesity alone* prevalence in the South and non-rural (suburban and urban) counties. Therefore, local-level intervention may need to consider whether they are targeting a population that has a high childhood overweight or obese prevalence or both. Understandably, the risk for adverse health outcomes and comorbidities is greatest among the obese but the overweight may require a different strategy to prevent a transition towards obesity.

The results of this study contribute to the limited amount of literature examining the socioeconomic and built environment conditions on childhood overweight and obesity, and the subsequent risks at a local level. Additionally, these findings may identify ecologic correlates among overweight and obese children at the county level to implement change. Although the parameter estimates were not large in magnitude, the associations were significant. This suggests that childhood obesity is a complex and multi-faceted issue and may be influenced by the combined effects of the social, economic and physical environments. These results suggest that more urban counties with indicators of reduced food access, increased levels of food assistance and poor adult health are at an increased risk for overweight and obesity among its adolescent residents.

A major strength of this study is the ability to use small area estimates nationwide to predict obesogenic environments at the county level. This study also benefits from the aforementioned strengths listed in Chapter 2.1 pertaining to the Bayesian modeling approach and large sample size of NSCH survey data.

Although the novel approach to obtain Bayesian predicted estimates is appealing, the model-based estimates may not equate to the 'true' prevalence of obesity among US adolescents due to many un- and undersampled counties. It was not possible to include the observed prevalence for every county since less than 7% (216) counties had no NSCH respondents and many had sparse data (only 200 counties with more than 100 respondents). Additionally, this study suffers limitations due to its cross-sectional design and non-representativeness to younger children and multiple race-ethnic subgroups. The observed association of overweight/obesity prevalence especially obesity prevalence and the county-level contextual variables may be unstable due to the small number of survey respondent data per county. As stated in Chapter 2.1, the design of NSCH study design is subject to several shortcomings including those inherent to sample surveys and possible outcome misclassification due to the subjective nature of height and weight measurements from the selected child's parent or guardian.[203,204]

An implication of this study is to identify contextual characteristics of the social and built environments that may alleviate the high burden of childhood obesity in many US counties. These results suggest that the relationship between childhood obesity is complex and multifactorial. The estimates provided from this model-based approach are likely to be useful at the local-, state-, and national-level by policymakers and public health agencies. This ecologic analysis may identify a unique risk profile to identify culturally appropriate interventions and best allocate resources. A solution requires local-, state, and federal government involvement paired with community-based and private sector collaboration.

Future research that would contribute to this topic would include a multi-level approach to examine indicators of the social, economic and physical environments at the individual and county level. A principal component analysis using these model-based prevalence estimates and contextual variables may elucidate a childhood obesity index that acts to predict overweight and obesity prevalence among US adolescents at the county level. This would substantially reduce the number of covariates in the model creating an easier interpretation of findings.

TABLES

Table 1. Basic descriptive statistics of state-level, public use and county-level, restricted use 2003 and 2007 NSCH data (n, % [unweighted]) for US children aged 10-17 years.

	Public Use NSCH Data set						Final NSCH Data set*					
	2003		2007		Pooled		2003		2007		Pooled	
Total	48742		45897		94639		48742		45897		94639	
Exclude data with missing BMI	46707	95.8%	44101	96.1%	90808	95.95%	45833	94.0%	44101	96.1%	89934	95.0%
# of counties	--		--		--		2818	89.7%	2633	83.8%	2925	93.1%
BMI Classification												
Under/Normal weight	33168	71.0%	31307	71.0%	64475	71.0%	32551	71.0%	31307	71.0%	63858	71.0%
Overweight including obesity	13539	29.0%	12794	29.0%	26333	29.0%	13282	29.0%	12794	29.0%	26076	29.0%
Overweight alone	7119	15.2%	6754	15.3%	13873	15.3%	6986	15.2%	6754	15.3%	13740	15.3%
Obesity alone	6420	13.7%	6040	13.7%	12460	13.7%	6296	13.7%	6040	13.7%	12336	13.7%
Age												
10-14 years	27502	58.9%	24869	56.4%	52371	57.7%	26993	58.9%	24869	56.4%	51862	57.7%
15-17 years	19205	41.1%	19232	43.6%	38437	42.3%	18840	41.1%	19232	43.6%	38072	42.3%
Sex												
Female	22635	48.5%	21111	47.9%	43746	48.2%	22192	48.4%	21111	47.9%	43303	48.1%
Male	24072	51.5%	22990	52.1%	47062	51.8%	23641	51.6%	22990	52.1%	46631	51.9%
Race-ethnicity												
Non-Hispanic White	34013	72.8%	31055	70.4%	65068	71.7%	33713	73.6%	31055	70.4%	64768	72.0%
All other races or missing	12694	27.2%	13046	29.6%	25740	28.3%	12120	26.4%	13046	29.6%	25166	28.0%

*With county identifiers, no missing BMI data and valid FIPS codes (a state-county FIPS code that was present in NSCH data and 2010 US Census TigerLine shapefile for US counties

Table 2. Basic descriptive statistics for model-based estimates for county-level overweight and obesity prevalence among 10-17 year old US children [Data source: 2003 and 2007 NSCH].

	Overweight including obesity				Overweight alone				Obesity alone			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Prevalence Estimate												
All (n=3141 counties)	30.7%	4.8%	8.4%	60.3%	15.8%	2.1%	1.9%	39.4%	15.2%	3.8%	1.4%	36.7%
Census Region												
Northeast (n=216)	28.9%	3.5%	18.4%	50.4%	15.6%	2.1%	1.9%	37.3%	13.4%	2.5%	8.8%	36.7%
Midwest (n=1054)	28.5%	3.0%	20.7%	42.3%	15.2%	1.3%	11.2%	22.4%	13.4%	2.3%	8.2%	23.9%
South (n=1421)	33.8%	4.1%	23.2%	51.9%	16.3%	1.9%	12.1%	25.0%	18.0%	3.3%	9.8%	30.7%
West (n=446)	27.0%	4.7%	8.4%	60.3%	15.5%	3.5%	5.3%	39.4%	11.6%	2.2%	1.4%	22.1%
Census Division												
New England (n=66)	27.3%	3.0%	21.3%	34.1%	15.1%	1.1%	13.1%	17.4%	12.0%	1.4%	9.0%	16.7%
Middle Atlantic (n=150)	29.7%	3.5%	18.4%	50.4%	15.9%	2.4%	1.9%	37.3%	14.0%	2.7%	8.8%	36.7%
East North Central (n=436)	29.8%	2.4%	24.0%	39.6%	15.4%	1.2%	12.3%	22.4%	14.6%	2.1%	10.4%	22.2%
West North Central (n=618)	27.5%	3.0%	20.7%	42.3%	15.1%	1.4%	11.2%	19.4%	12.5%	2.1%	8.2%	23.9%
South Atlantic (n=589)	32.7%	3.4%	23.6%	42.7%	16.1%	1.3%	12.2%	22.2%	17.0%	3.3%	9.8%	29.0%
East South Central (n=364)	37.9%	3.4%	29.9%	51.9%	18.0%	1.9%	13.4%	25.0%	20.5%	2.9%	13.6%	30.7%
West South Central (n=468)	32.1%	3.2%	23.2%	43.5%	15.2%	1.7%	12.1%	20.7%	17.1%	2.4%	11.7%	26.7%
Mountain (n=281)	25.8%	4.5%	8.4%	38.8%	14.8%	3.4%	5.3%	39.4%	11.1%	2.4%	1.4%	22.1%
Pacific (n=165)	29.2%	4.2%	22.6%	60.3%	16.9%	3.3%	7.3%	25.7%	12.4%	1.5%	10.3%	20.7%

Table 3. Basic descriptive statistics of county-level contextual variables.

	Mean	SD	Min	Max
Physical Activity				
Proportion of Workers that Walk to Work (n=3138)[a]	3.52%	3.79%	0%	71.66%
Recreation & fitness facilities/ 1,000 pop, 2008 (n=3140)[b]	0.08	0.09	0.00	1.50
Neighborhood Safety				
Violent crime rate (per 100,000 county population)[c]	0.03	0.02	0.00	0.29
Food environment				
% Low income & > 1 mi to store, 2006 (n=3108)[d]	23.60	11.68	0.00	79.80
% Low income & > 10 mi to store, 2006 (n=3108)[d]	5.57	9.89	0.00	70.74
% Households with no car & > 1 mi to store, 2006 (n=3108)[d]	3.98	2.60	0.00	27.91
% Households with no car & > 10 mi to store, 2006 (n=3108)[d]	0.77	1.51	0.00	16.36
Grocery stores/ 1,000 pop, 2008 (n=3140)[b]	0.28	0.24	0.00	3.14
Farmers' markets/ 1,000 pop, 2009 (n=3140)[b]	0.04	0.07	0.00	1.02
Convenience stores no gas/ 1,000 pop, 2008 (n=3140)[b]	0.07	0.10	0.00	1.67
Convenience stores with gas/ 1,000 pop, 2008 (n=3140)[b]	0.55	0.31	0.00	3.67
Fast-food restaurants/ 1,000 pop, 2008 (n=3140)[b]	0.81	0.62	0.00	17.51
Full-service restaurants/ 1,000 pop, 2008 (n=3140)[b]	0.58	0.32	0.00	7.01
Food assistance				
Total WIC redemptions ($1,000), 2009 (n=3005)[e]	$2,043.00	$9,009.00	0.00	$34,119.00
WIC-authorized stores/1,000 pop, 2009 (n=3005)[e]	0.25	0.23	0.00	4.55
Total SNAP benefits ($1,000), 2009 (n=3041)[f]	$11,904.32	$40,825.47	$50.00	$964,381.00
Average monthly SNAP benefits per recipient, 2009 (n=3036)[f]	$89.01	$29.68	$0.00	$1,044.00
SNAP-authorized stores/1,000 pop, 2009 (n=3137)[f]	0.88	0.45	$0.00	7.29
% of low-income households who are SNAP recipients, 2007 (n=3138)[f]	31.39	13.18	$0.00	76.89
% Students free- and reduced-price lunch eligible, 2008 (n=3122)[g]	47.19	16.81	$0.00	99.49
Adult Health				
Adult diabetes rate, 2008 (n=3140)[h]	9.91	2.06	3.00	18.20
Adult obesity rate, 2008 (n=3140)[h]	28.93	3.71	11.70	43.70
Socioeconomic				
Median household income, 2005 (n=3140)[i]	$39,158.30	$10,084.92	$16,868.00	$98,245.00
Child poverty (less than 18 years of age), 2005 (n=3140)[i]	21.36	9.33	2.50	70.10
Gini Coefficient (n=3138)[a]	0.43	0.04	0.20	0.62
Unemployment rate, 2005 (n=3133)[i]	5.42	1.82	1.80	20.90
% Black (all ages)	8.79%	14.39%	0.00%	86.76%
% Hispanic (all ages)	7.53%	12.76%	0.00%	98.63%
Rural status[k]	1357 (43.2%)			

[a]American Community Survey (5-year estimate), 2005-2009
[b]U.S. Census Bureau, County Business Patterns, 2008 (Accessed via USDA's Food Environment Atlas)
[c]Uniform Crime Reporting Program Data: County-level Detailed Arrest and Offense Data, Average of 2003 and 2007 data (Accessed via Interdisciplinary Consortium of Social and Political Research)
[d]Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences: Report to Congress, 2006
[e]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service, USDA, 2009
[f]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, SNAP Benefits Redemption Division, Food and Nutrition Service, USDA, 2009
[g]Common Core of Data, National Center for Education Statistics, U.S. Department of Education, 2008
[h]Behavioral Risk F S S data from Center for Disease Control and Prevention, 2008
[i]U.S. Census Bureau, Small Area Income and Poverty Estimates, 2005
[i]Bureau of Labor Statistics, 2005
[k]NCHS Urban/Rural Classification Scheme for Counties, 2006

Table 4. Model-based prevalence estimates and basic statistics for county-level covariates for counties that are below the national overweight and obesity means (posterior mean and 95% credible intervals exclude the national mean using 2003 and 2007 NSCH).

	BELOW NATIONAL MEAN											
	Overweight including obesity (n=177)				Overweight alone (n=18)				Obesity alone (n=356)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Prevalence Estimate[a]	22.27%	2.20%	8.38%	26.28%	8.72%	3.32%	1.92%	13.12%	10.08%	1.17%	1.39%	13.40%
Physical Activity												
Proportion of Workers that Walk to Work[b]	4.99%	3.38%	0.76%	22.02%	3.95%	2.65%	1.12%	11.16%	5.71%	4.08%	0.71%	25.83%
Recreation & fitness facilities/ 1,000 pop, 2008[c]	0.14	0.17	0.00	1.50	0.10	0.06	0.00	0.18	0.12	0.14	0.00	1.50
Neighborhood Safety												
Violent crime rate (per 100,000 county population)[d]	0.02	0.02	0.00	0.09	0.03	0.02	0.01	0.09	0.02	0.02	0.00	0.12
Food environment												
% Low income & > 1 mi to store, 2006[e]	18.51	10.95	1.78	51.55	14.68	11.50	2.84	38.54	19.54	10.90	0.00	51.98
% Low income & > 10 mi to store, 2006[e]	8.58	11.95	0.00	51.55	1.61	2.46	0.00	8.44	8.42	12.03	0.00	51.98
% Households with no car & > 1 mi to store, 2006 [e]	2.48	1.49	0.40	10.05	2.39	1.64	0.51	6.18	2.52	1.44	0.00	10.05
% Households with no car & > 10 mi to store, 2006 [e]	0.99	1.55	0.00	10.05	0.23	0.50	0.00	2.09	0.89	1.50	0.00	10.05
Grocery stores/ 1,000 pop, 2008[c]	0.36	0.34	0.00	2.23	0.23	0.18	0.08	0.88	0.37	0.33	0.00	2.31
Farmers' markets/ 1,000 pop, 2009[c]	0.07	0.14	0.00	1.02	0.04	0.04	0.00	0.16	0.06	0.11	0.00	1.02
Convenience stores no gas/ 1,000 pop, 2008[c]	0.06	0.12	0.00	1.25	0.10	0.12	0.00	0.44	0.07	0.13	0.00	1.25
Convenience stores with gas/ 1,000 pop, 2008 [c]	0.51	0.33	0.00	1.96	0.32	0.18	0.00	0.76	0.52	0.41	0.00	3.67
Fast-food restaurants/ 1,000 pop, 2008[c]	1.12	0.77	0.00	5.23	1.06	0.61	0.53	3.08	1.21	0.91	0.00	8.56
Full-service restaurants/ 1,000 pop, 2008[c]	0.36	0.34	0.00	2.23	0.70	0.22	0.00	0.98	0.68	0.37	0.00	2.84
Food assistance												
Total WIC redemptions ($1,000), 2009[f]	$1,885.67	$4,210.64	$0.00	$28,643.60	$4,295.55	$6,716.82	$0.00	$22,555.18	$1,750.43	$5,767.16	$0.00	$85,844.83
WIC-authorized stores/1,000 pop, 2009 [f]	0.32	0.31	0.00	1.55	0.16	0.12	0.00	0.43	0.30	0.36	0.00	4.55
Total SNAP benefits ($1,000), 2009[g]	$9,848.84	$24,164.69	$52.00	$147,272.00	$28,527.22	$42,522.95	$185.00	$121,291.00	$10,681.39	$34,993.76	$52.00	$413,055.00
Average monthly SNAP	$90.50	$19.99	$28.00	$190.00	$91.72	$22.75	$28.00	$141.00	$101.84	$75.21	$28.00	$1,044.00

benefits per recipient, 2009[g]												
SNAP-authorized stores/1,000 pop, 2009[g]	0.71	0.47	0.00	3.85	0.59	0.20	0.18	0.94	0.71	0.39	0.00	2.61
% of low-income households who are SNAP recipients, 2007 [g]	19.12	9.06	0.00	53.72	27.45	12.39	8.63	53.80	20.24	10.59	1.12	51.01
% Students free- and reduced-price lunch eligible, 2008[h]	32.70	11.16	4.98	69.39	40.57	17.23	4.98	69.39	33.32	12.17	0.00	69.39
Adult Health												
Adult diabetes rate, 2008 [i]	7.54	1.63	3.40	11.70	7.73	2.06	3.40	11.30	7.61	1.52	3.40	11.70
Adult obesity rate, 2008 [i]	24.82	4.24	11.70	31.10	24.47	4.26	16.00	31.10	24.67	4.07	11.70	35.80
Socioeconomic												
Median household income, 2005[j]	$45,845.12	$12,554.46	$25,917.00	$92,439.00	$47,579.22	$13,400.48	$31,809.00	$90,143.00	$44,791.05	$12,111.08	$25,577.00	$94,173.00
Child poverty (less than 18 years of age), 2005[j]	13.58	5.75	3.00	45.30	16.66	7.56	3.20	36.30	15.17	6.44	2.50	45.30
Gini Coefficient[b]	0.42	0.03	0.32	0.53	0.43	0.04	0.35	0.49	0.42	0.04	0.27	0.62
Unemployment rate, 2005[k]	4.27	1.10	2.40	10.40	4.92	1.65	3.10	10.40	4.49	1.47	1.80	10.50
% Black (all ages)[b]	1.51%	3.00%	0.00%	16.46%	4.20%	5.67%	0.00%	21.16%	1.28%	2.56%	0.00%	22.24%
% Hispanic (all ages)[b]	4.89%	5.61%	0.00%	45.64%	8.52%	10.57%	0.49%	45.64%	5.09%	5.01%	0.00%	30.58%
Rural status[l]	85 (48.02%)				4 (22.22%)				171 (48.03%)			

[a]Model-based prevalence estimates using 2003 and 2007 National Survey of Children's Health survey data

[b]American Community Survey (5-year estimate), 2005-2009

[c]U.S. Census Bureau, County Business Patterns, 2008 (Accessed via USDA's Food Environment Atlas)

[d]Uniform Crime Reporting Program Data: County-level Detailed Arrest and Offense Data, 2003 and 2007 (Accessed via Interdisciplinary Consortium of Social and Political Research)

[e]Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences: Report to Congress, 2006

[f]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service, USDA, 2009

[g]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, SNAP Benefits Redemption Division, Food and Nutrition Service, USDA, 2009

[h]Common Core of Data, National Center for Education Statistics, U.S. Department of Education, 2008

[i]Behavioral Risk Factor Surveillence System data from Center for Disease Control and Prevention, 2008

[j]U.S. Census Bureau, Small Area Income and Poverty Estimates, 2005

[k]Bureau of Labor Statistics, 2005

[l]NCHS Urban/Rural Classification Scheme for Counties, 2006

Table 5. Model-based prevalence estimates and basic statistics for county-level covariates for counties that are above the national overweight and obesity means (posterior mean and 95% credible intervals exclude the national mean using 2003 and 2007 NSCH).

	ABOVE NATIONAL MEAN											
	Overweight including obesity (n=123)				Overweight alone (n=27)				Obesity alone (n=36)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Prevalence Estimate[a]	41.94%	3.43%	35.20%	60.27%	23.58%	4.59%	18.59%	39.42%	26.07%	2.97%	19.65%	36.73%
Physical Activity												
Proportion of Workers that Walk to Work [b]	2.72%	2.74%	0.09%	20.99%	3.19%	3.96%	0.22%	20.99%	3.14%	2.64%	0.37%	11.30%
Recreation & fitness facilities/ 1,000 pop, 2008[c]	0.05	0.05	0.00	0.27	0.08	0.07	0.00	0.27	0.06	0.05	0.00	0.19
Neighborhood Safety												
Violent crime rate (per 100,000 county population)[d]	0.05	0.04	0.00	0.23	0.05	0.02	0.02	0.10	0.06	0.04	0.01	0.15
Food environment												
% Low income & > 1 mi to store, 2006[e]	33.42	13.45	0.00	64.62	27.78	14.76	0.00	50.67	29.26	14.75	0.03	60.40
% Low income & > 10 mi to store, 2006[e]	4.76	5.90	0.00	31.02	3.60	4.74	0.00	18.02	3.57	4.35	0.00	14.00
% Households with no car & > 1 mi to store, 2006 [e]	7.39	3.71	0.00	18.60	6.38	3.98	0.00	13.31	6.46	3.76	0.03	15.83
% Households with no car & > 10 mi to store, 2006 [e]	1.08	1.55	0.00	9.39	0.84	1.32	0.00	5.13	0.79	1.09	0.00	3.42
Grocery stores/ 1,000 pop, 2008[c]	0.24	0.12	0.00	0.79	0.24	0.14	0.06	0.69	0.25	0.11	0.09	0.64
Farmers' markets/ 1,000 pop, 2009[c]	0.03	0.04	0.00	0.24	0.01	0.02	0.00	0.09	0.03	0.03	0.00	0.09
Convenience stores no gas/ 1,000 pop, 2008[c]	0.08	0.07	0.00	0.45	0.08	0.05	0.00	0.17	0.10	0.07	0.00	0.31
Convenience stores with gas/ 1,000 pop, 2008 [c]	0.64	0.27	0.00	1.43	0.56	0.27	0.02	1.07	0.61	0.27	0.03	1.21
Fast-food restaurants/ 1,000 pop, 2008[c]	0.45	0.30	0.00	2.50	0.60	0.51	0.00	2.50	0.50	0.23	0.00	1.13
Full-service restaurants/ 1,000 pop, 2008[c]	0.55	0.23	0.00	1.30	0.58	0.25	0.10	1.30	0.57	0.22	0.22	1.27
Food assistance												
Total WIC redemptions ($1,000), 2009[f]	$5,275.83	$17,369.68	$1.77	$116,919.68	$6,826.49	$7,247.75	$78.37	$26,004.86	$12,035.02	$29,543.59	$141.94	$116,919.68
WIC-authorized stores/1,000 pop, 2009 [f]	0.24	0.16	0.01	0.78	0.16	0.09	0.07	0.37	0.23	0.12	0.04	0.55
Total SNAP benefits ($1,000), 2009[g]	$27,274.84	$102,939.34	$577.00	$964,381.00	$35,068.52	$68,142.21	$490.00	$350,675.00	$57,129.36	$171,789.94	$1,299.00	$964,381.00

Average monthly SNAP benefits per recipient, 2009[g]	$86.73	$13.95	$48.00	$134.00	$96.37	$16.98	$66.00	$134.00	$87.81	$11.55	$62.00	$108.00
SNAP-authorized stores/1,000 pop, 2009[g]	1.25	0.45	0.48	2.59	1.07	0.39	0.25	1.87	1.23	0.49	0.48	2.45
% of low-income households who are SNAP recipients, 2007 [g]	42.25	10.13	18.11	68.97	39.85	11.86	15.37	57.82	42.92	9.30	18.11	57.32
% Students free- and reduced-price lunch eligible, 2008[h]	73.85	17.03	22.18	99.49	68.87	25.31	20.09	99.24	71.18	16.09	44.60	99.24
Adult Health												
Adult diabetes rate, 2008 [i]	13.04	1.92	6.80	17.50	11.86	3.25	5.20	15.90	12.40	2.14	8.30	15.70
Adult obesity rate, 2008 [i]	34.98	4.01	16.10	42.70	33.40	6.45	16.10	42.70	33.73	4.59	21.20	42.10
Socioeconomic												
Median household income, 2005[j]	$30,226.76	$7,345.78	$19,407.00	$55,561.00	$36,431.59	$12,399.74	$20,916.00	$61,018.00	$31,216.33	$7,676.36	$18,488.00	$48,919.00
Child poverty (less than 18 years of age), 2005[j]	35.03	10.44	10.80	59.50	31.30	14.12	10.90	59.50	34.96	12.44	18.80	58.10
Gini Coefficient[b]	0.47	0.04	0.37	0.60	0.47	0.04	0.39	0.60	0.47	0.03	0.40	0.54
Unemployment rate, 2005[k]	8.01	2.11	3.90	15.30	8.44	2.75	4.20	15.30	7.25	2.08	4.40	12.70
% Black (all ages)[b]	41.09%	22.17%	0.08%	86.76%	42.01%	27.58%	0.00%	86.76%	35.09%	24.85%	1.47%	73.97%
% Hispanic (all ages)[b]	3.04%	5.76%	0.00%	51.17%	3.68%	4.91%	0.00%	24.49%	4.94%	10.70%	0.15%	51.17%
Rural status[l]	56 (45.53%)				6 (22.22%)				14 (38.89%)			

[a]Model-based prevalence estimates using 2003 and 2007 National Survey of Children's Health survey data
[b]American Community Survey (5-year estimate), 2005-2009
[c]U.S. Census Bureau, County Business Patterns, 2008 (Accessed via USDA's Food Environment Atlas)
[d]Uniform Crime Reporting Program Data: County-level Detailed Arrest and Offense Data, 2003 and 2007 (Accessed via Interdisciplinary Consortium of Social and Political Research)
[e]Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences: Report to Congress, 2006
[f]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service, USDA, 2009
[g]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, SNAP Benefits Redemption Division, Food and Nutrition Service, USDA, 2009
[h]Common Core of Data, National Center for Education Statistics, U.S. Department of Education, 2008
[i]Behavioral Risk Factor Surveillence System data from Center for Disease Control and Prevention, 2008
[j]U.S. Census Bureau, Small Area Income and Poverty Estimates, 2005
[k]Bureau of Labor Statistics, 2005
[l]NCHS Urban/Rural Classification Scheme for Counties, 2006

Table 6. Model fit comparison assessing for best fit when considering all non-collinear covariates, geography (rurality and Census-based region) and population (normal and log transformed total population and population density.

	Rural and region	Rural, region and total population	Rural, region, and log total population	Rural, region and population density	Rural, region and log population density
Outcome 1: Overweight including obesity					
Deviance	0.9798	0.9778	0.9768	0.9692	0.9663
Pearson Chi-Square	1.126	1.1144	1.1152	1.0965	1.1014
Full Log (Likelihood)	-15880.4152	-15845.4996	-15862.1629	-15697.3858	-15742.7734
AIC	31806.8304	31736.9993	31768.3258	31440.7716	31525.5468
Outcome 2: Overweight alone					
Deviance	0.9625	0.9625	0.9584	0.9655	0.9622
Pearson Chi-Square	0.9805	0.9805	0.9762	0.9826	0.9804
Full Log (Likelihood)	-15070.1163	-15070.1163	-14928.8099	-14815.9798	-15075.6617
AIC	30170.2326	30170.2326	29887.6198	29665.9595	30177.3234
Outcome 3: Obesity alone					
Deviance	0.9723	0.9723	0.9723	0.9723	0.9694
Pearson Chi-Square	1.0058	1.0058	1.0058	1.0058	1.0034
Full Log (Likelihood)	-16918.8049	-16918.8049	-16918.8049	-16918.8049	-16985.027
AIC	33881.6097	33881.6097	33881.6097	33881.6097	34006.054

Table 7. Negative binomial regression model using standardized covariates (following tests of correlation and collinearity) for Overweight including obesity prevalence among US adolescents.

Model: Negative binomial regression	Overweight including obesity					
	parameter estimate	**standard error**	**Wald 95% confidence limits**		**Wald chi-sq**	**p-value**
Intercept	-1.2623	0.0067	-1.2754	-1.2493	35986.20	<.0001
Physical Activity						
Proportion of Workers that Walk to Work (n=3138)[a]	0.0134	0.0040	0.0055	0.0212	11.17	0.0008
Neighborhood Safety						
Violent crime rate per 100,000 county residents (n=2818)[c]	0.0070	0.0024	0.0024	0.0116	8.94	0.0028
Food environment						
% Households with no car & > 1 mi to store, 2006 (n=3108)[d]	0.0059	0.0029	0.0002	0.0117	4.07	0.0437
Convenience stores no gas/ 1,000 pop, 2008 (n=3140)[b]	-0.0108	0.0025	-0.0157	-0.0060	19.21	<.0001
Food assistance						
WIC-authorized stores/1,000 pop, 2009 (n=3005)[e]	-0.0137	0.0037	-0.0209	-0.0065	14.06	0.0002
Average monthly SNAP benefits per recipient, 2009 (n=3036)[f]	0.0060	0.0027	0.0008	0.0112	5.08	0.0242
Proportion of low-income households who are SNAP recipients, 2007 (n=3138)[f]	0.0156	0.0029	0.0099	0.0213	28.83	<.0001
% Students reduced- and free-lunch eligible, 2008 (n=3122)[g]	0.0120	0.0037	0.0047	0.0192	10.45	0.0012
Adult Health						
Adult diabetes rate, 2008 (n=3140)[h]	0.0470	0.0037	0.0397	0.0542	160.18	<.0001
Adult obesity rate, 2008 (n=3140)[h]	0.0301	0.0031	0.0241	0.0362	95.41	<.0001
Socioeconomic						
Median household income, 2005 (n=3140)[i]	0.0146	0.0040	0.0067	0.0225	13.21	0.0003
% Black (all ages)[a]	0.0083	0.0029	0.0025	0.0141	7.99	0.0047
% Hispanic (all ages)[a]	0.0485	0.0034	0.0418	0.0552	201.27	<.0001
Unemployment[j]	0.0067	0.0026	0.0016	0.0119	6.55	0.0105
Child poverty[i]	0.0112	0.0049	0.0017	0.0208	5.31	0.0211
Geography and Population						
Rural (suburban)[k]	0.0253	0.0047	0.0160	0.0346	28.56	<.0001
Rural (urban)[k]	0.0228	0.0078	0.0075	0.0380	8.56	0.0034
Region 1 (Northeast)	0.0695	0.0085	0.0529	0.0862	67.11	<.0001
Region 2 (Midwest)	0.0302	0.0071	0.0163	0.0440	18.25	<.0001
Region 3 (South)	0.0845	0.0076	0.0697	0.0993	125.30	<.0001
Population density	0.0000	0.0000	0.0000	0.0000	38.07	<.0001

[a]American Community Survey (5-year estimate), 2005-2009
[b]U.S. Census Bureau, County Business Patterns, 2008 (Accessed via USDA's Food Environment Atlas)
[c]Uniform Crime Reporting Program Data: County-level Detailed Arrest and Offense Data, 2003 and 2007 (Accessed via Interdisciplinary Consortium of Social and Political Research)
[d]Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences: Report to Congress, 2006
[e]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service, USDA, 2009
[f]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, SNAP Benefits Redemption Division, Food and Nutrition Service, USDA, 2009
[g]Common Core of Data, National Center for Education Statistics, U.S. Department of Education, 2008
[h]Behavioral Risk F S S data from Center for Disease Control and Prevention, 2008
[i]U.S. Census Bureau, Small Area Income and Poverty Estimates, 2005
[j]Bureau of Labor Statistics, 2005
[k]NCHS Urban/Rural Classification Scheme for Counties, 2006

Table 8. Negative binomial regression model using standardized covariates (following tests of correlation and collinearity) for Overweight alone prevalence among US adolescents.

Model: Negative binomial regression	Overweight alone					
	parameter estimate	**standard error**	**Wald 95% confidence limits**		**Wald chi-sq**	**p-value**
Intercept	-1.8556	0.0025	-1.8605	-1.8508	566642.00	<.0001
Physical Activity						
Proportion of Workers that Walk to Work (n=3138)[a]	0.0172	0.0040	0.0094	0.0250	18.75	<.0001
Recreation & fitness facilities/ 1,000 pop, 2008 (n=3140)[b]	0.0085	0.0033	0.0020	0.0149	6.52	0.0106
Neighborhood Safety						
Violent crime rate per 100,000 county residents (n=2818)[c]	0.0191	0.0026	0.0140	0.0241	54.89	<.0001
Food environment						
Convenience stores with gas/ 1,000 pop, 2008 (n=3140)[b]	-0.0081	0.0036	-0.0153	-0.0010	4.95	0.0261
Grocery stores/ 1,000 pop, 2008 (n=3140)[b]	0.0131	0.0050	0.0033	0.0229	6.93	0.0085
Full-service restaurants/ 1,000 pop, 2008 (n=3140)[b]	-0.0108	0.0036	-0.0178	-0.0039	9.32	0.0023
Food assistance						
WIC-authorized stores/1,000 pop, 2009 (n=3005)[e]	-0.0165	0.0055	-0.0273	-0.0057	8.91	0.0028
WIC redemptions per county, 2009 (n=3005)[e]	0.0087	0.0042	0.0004	0.0169	4.25	0.0392
Total SNAP benefits ($1,000), 2009 (n=3041)[f]	-0.0095	0.0046	-0.0184	-0.0005	4.25	0.0392
Adult Health						
Adult diabetes rate, 2008 (n=3140)[h]	0.0282	0.0038	0.0207	0.0357	53.91	<.0001
Adult obesity rate, 2008 (n=3140)[h]	0.0292	0.0035	0.0223	0.0361	68.48	<.0001
Socioeconomic						
Median household income, 2005 (n=3140)[i]	0.0071	0.0032	0.0008	0.0133	4.92	0.0266
% Hispanic (all ages)[a]	0.0183	0.0038	0.0109	0.0257	23.44	<.0001
Unemployment[j]	0.0098	0.0029	0.0041	0.0155	11.48	0.0007
Geography and Population						
Population density	0.0000	0.0000	0.0000	0.0000	8.41	0.0037

[a]American Community Survey (5-year estimate), 2005-2009

[b]U.S. Census Bureau, County Business Patterns, 2008 (Accessed via USDA's Food Environment Atlas)

[c]Uniform Crime Reporting Program Data: County-level Detailed Arrest and Offense Data, 2003 and 2007 (Accessed via Interdisciplinary Consortium of Social and Political Research)

[d]Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences: Report to Congress, 2006

[e]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service, USDA, 2009

[f]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, SNAP Benefits Redemption Division, Food and Nutrition Service, USDA, 2009

[g]Common Core of Data, National Center for Education Statistics, U.S. Department of Education, 2008

[h]Behavioral Risk F S S data from Center for Disease Control and Prevention, 2008

[i]U.S. Census Bureau, Small Area Income and Poverty Estimates, 2005

[j]Bureau of Labor Statistics, 2005

[k]NCHS Urban/Rural Classification Scheme for Counties, 2006

Table 9. Negative binomial regression model using standardized covariates (following tests of correlation and collinearity) for Obesity alone prevalence among US adolescents.

Model: Negative binomial regression	Obesity alone					
	parameter estimate	**standard error**	**Wald 95% confidence limits**		**Wald chi-sq**	**p-value**
Intercept						
Physical Activity						
Recreation & fitness facilities/ 1,000 pop, 2008 (n=3140)[b]	-0.0077	0.0036	-0.0148	-0.0007	4.68	0.0305
Food environment						
% Households with no car & > 1 mi to store, 2006 (n=3108)[d]	0.0160	0.0044	0.0074	0.0246	13.41	0.0002
% Households with no car & > 10 mi to store, 2006 (n=3108)[d]	-0.0161	0.0039	-0.0238	-0.0084	16.73	<.0001
Convenience stores no gas/ 1,000 pop, 2008 (n=3140)[b]	-0.0161	0.0035	-0.0229	-0.0093	21.53	<.0001
Food assistance						
Average monthly SNAP benefits per recipient, 2009 (n=3036)[f]	0.0116	0.0036	0.0045	0.0186	10.39	0.0013
Proportion of low-income households who are SNAP recipients, 2007 (n=3138)[f]	0.0299	0.0041	0.0219	0.0379	53.70	<.0001
% Students reduced- and free-lunch eligible, 2008 (n=3122)[g]	0.0132	0.0054	0.0025	0.0239	5.89	0.0152
Adult Health						
Adult diabetes rate, 2008 (n=3140)[h]	0.0668	0.0054	0.0562	0.0775	150.88	<.0001
Adult obesity rate, 2008 (n=3140)[h]	0.0196	0.0047	0.0104	0.0289	17.41	<.0001
Socioeconomic						
Median household income, 2005 (n=3140)[i]	0.0167	0.0059	0.0052	0.0282	8.03	0.0046
% Black (all ages)	0.0124	0.0038	0.0049	0.0199	10.47	0.0012
% Hispanic (all ages)	0.0698	0.0051	0.0598	0.0798	187.74	<.0001
Gini Coefficient (n=3138)[a]	0.0104	0.0036	0.0034	0.0174	8.38	0.0038
Unemployment	0.0212	0.0038	0.0137	0.0286	30.91	<.0001
Child poverty	0.0143	0.0072	0.0003	0.0283	3.98	0.046
Geography and Population						
Rural (suburban)	0.0365	0.0066	0.0235	0.0495	30.30	<.0001
Rural (urban)	0.0414	0.0112	0.0194	0.0633	13.69	0.0002
Region 1 (Northeast)	0.1326	0.0130	0.1071	0.1582	103.80	<.0001
Region 2 (Midwest)	0.1299	0.0106	0.1090	0.1507	149.56	<.0001
Region 3 (South)	0.2470	0.0116	0.2243	0.2696	456.45	<.0001

[a]American Community Survey (5-year estimate), 2005-2009
[b]U.S. Census Bureau, County Business Patterns, 2008 (Accessed via USDA's Food Environment Atlas)
[c]Uniform Crime Reporting Program Data: County-level Detailed Arrest and Offense Data, 2003 and 2007 (Accessed via Interdisciplinary Consortium of Social and Political Research)
[d]Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences: Report to Congress, 2006
[e]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service, USDA, 2009
[f]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, SNAP Benefits Redemption Division, Food and Nutrition Service, USDA, 2009
[g]Common Core of Data, National Center for Education Statistics, U.S. Department of Education, 2008
[h]Behavioral Risk F S S data from Center for Disease Control and Prevention, 2008
[i]U.S. Census Bureau, Small Area Income and Poverty Estimates, 2005
[i]Bureau of Labor Statistics, 2005
[k]NCHS Urban/Rural Classification Scheme for Counties, 2006

FIGURES

Figure 1. Model-based predicted estimates of *overweight including obesity* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data [Census region model]

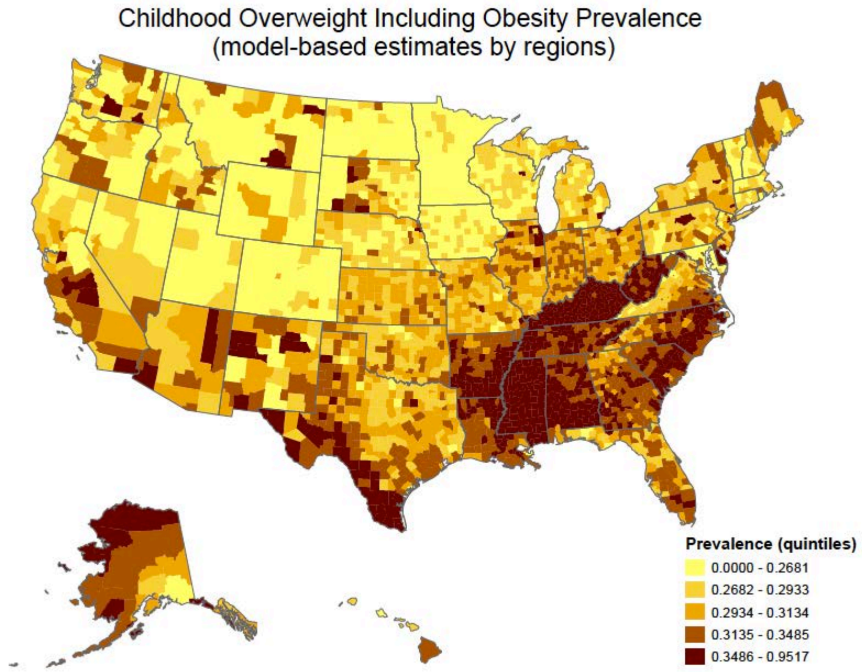


Figure 2. Model-based predicted estimates of *overweight alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data [Census region model]

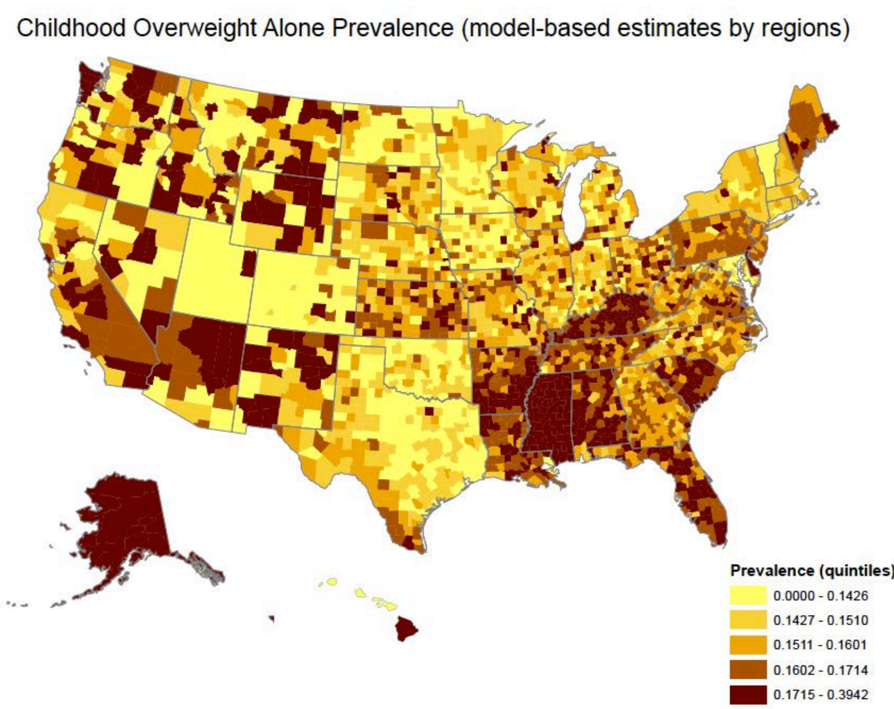


Figure 3. Model-based predicted estimates of *obesity alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data [Census region model]

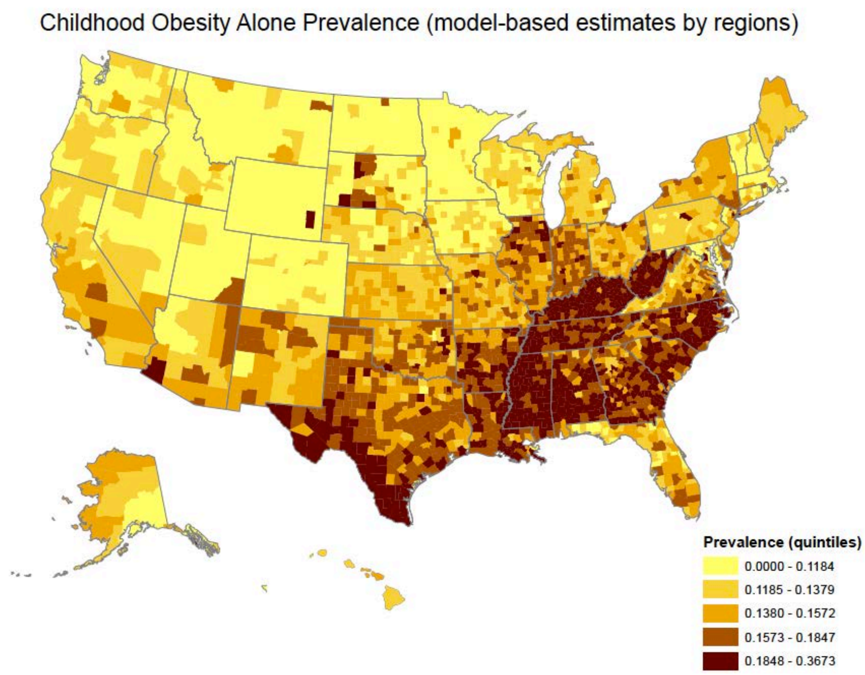


Figure 4. Model-based predicted estimates of *Overweight including obesity* prevalence among US adolescents (10-17 years) for US counties below and above the national mean (posterior mean and 95% credible interval excludes the national mean. [Data source: 2003 and 2007 NSCH data]

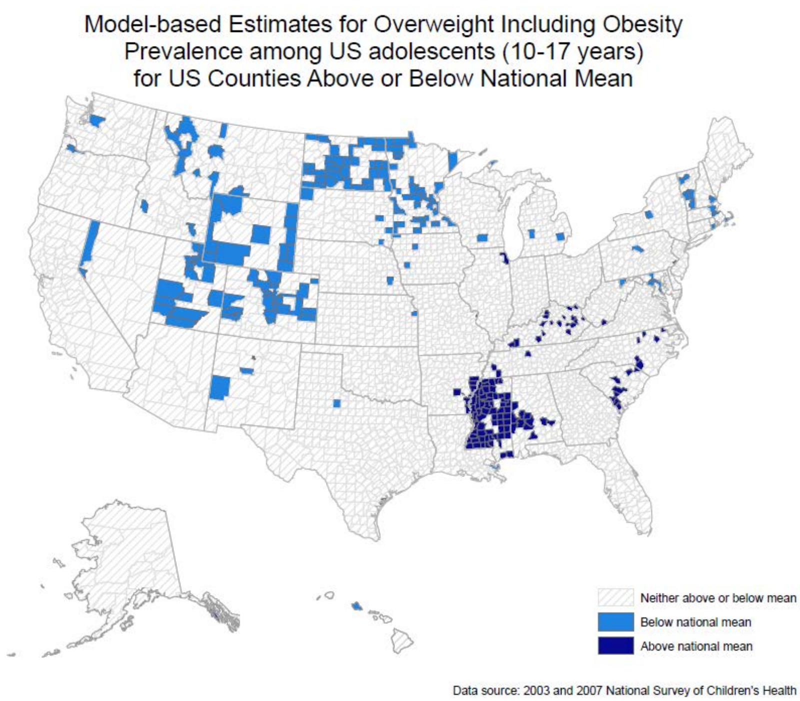


Figure 5. Model-based predicted estimates of *Overweight alone* prevalence among US adolescents (10-17 years) for US counties below and above the national mean (posterior mean and 95% credible interval excludes the national mean. [Data source: 2003 and 2007 NSCH data]

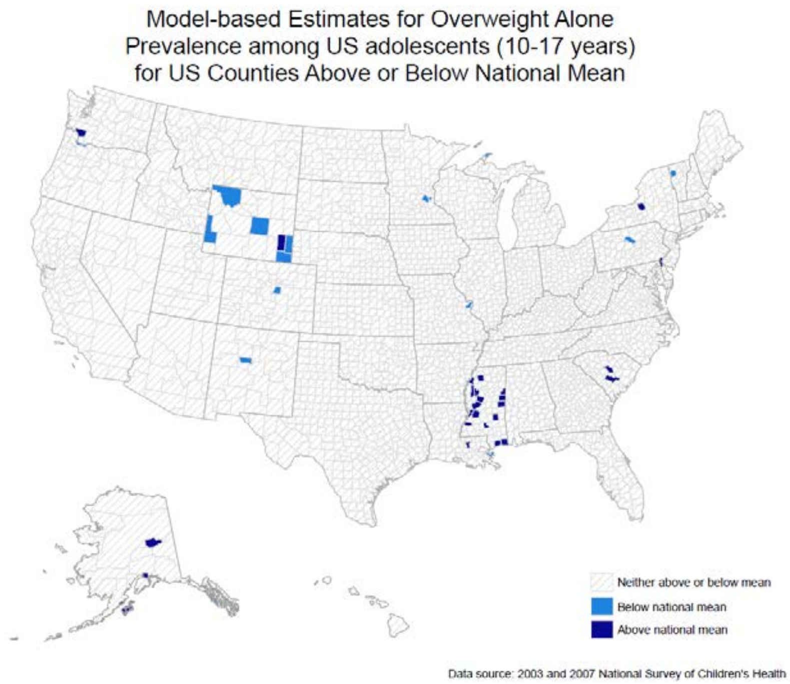


Figure 6. Model-based predicted estimates of *Obesity alone* prevalence among US adolescents (10-17 years) for US counties below and above the national mean (posterior mean and 95% credible interval excludes the national mean. [Data source: 2003 and 2007 NSCH data]

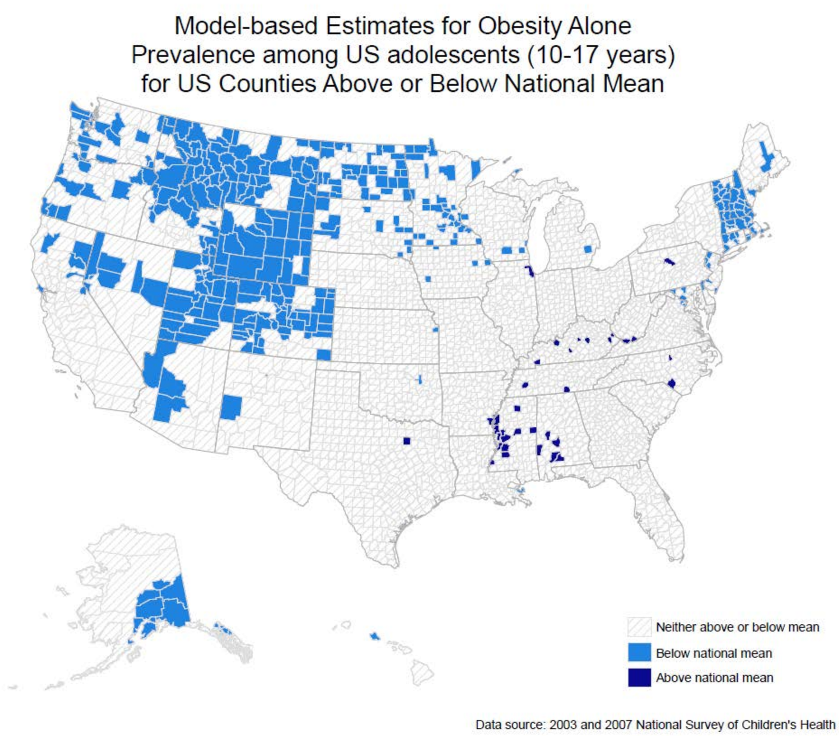


Figure 7. Model-based predicted estimates of *Overweight including obesity* prevalence among US adolescents (10-17 years) for US counties in the lowest and highest decile of the mean. [Data source: 2003 and 2007 NSCH data]

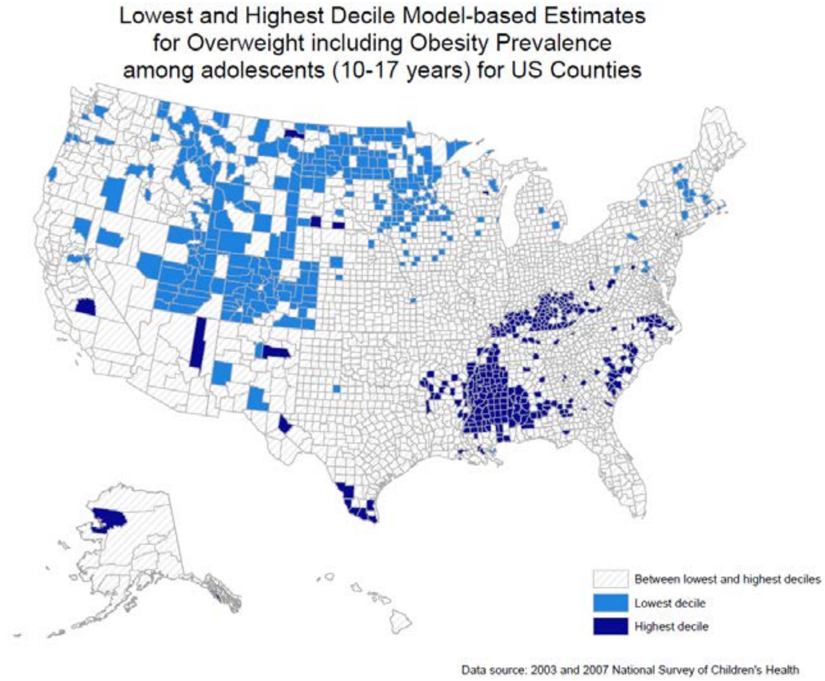


Figure 8. Model-based predicted estimates of *Overweight alone* prevalence among US adolescents (10-17 years) for US counties in the lowest and highest decile of the mean. [Data source: 2003 and 2007 NSCH data]

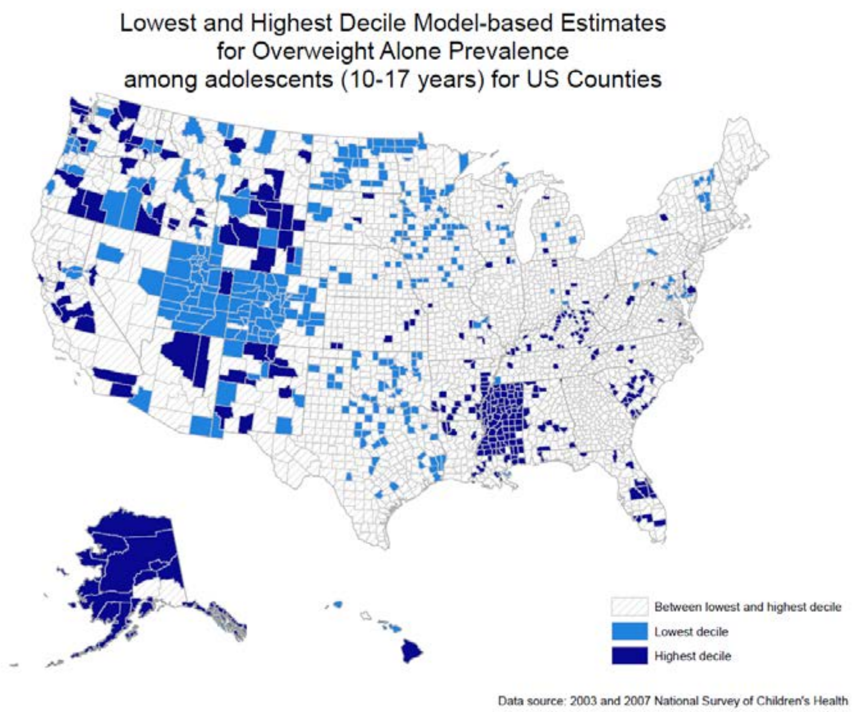


Figure 9. Model-based predicted estimates of *Obesity alone* prevalence among US adolescents (10-17 years) for US counties in the lowest and highest decile of the mean. [Data source: 2003 and 2007 NSCH data]

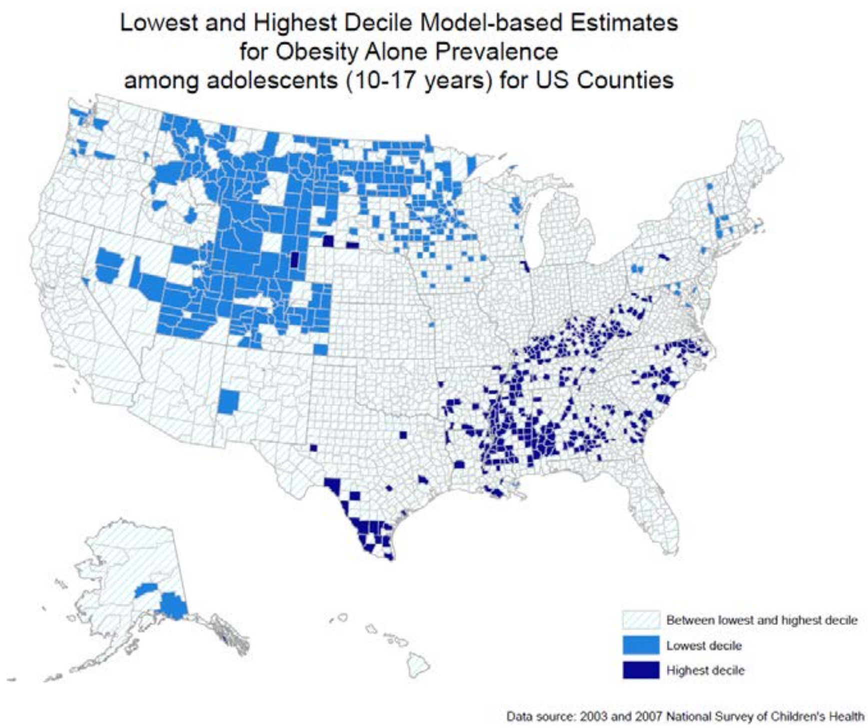


Figure 10. Sensitivity results for model-based *overweight including obesity* prevalence estimates among US children (10-17 years) for all US counties. [Data source: 2003 and 2007 NSCH]

Scatterplots of observed design-based vs. predicted (figures a-c) model-based *overweight including obesity* prevalence estimates and by region and division models (figures d and e) among US children (10-17 years) for all US counties modeled by Census region. [Data source: 2003 and 2007 NSCH]

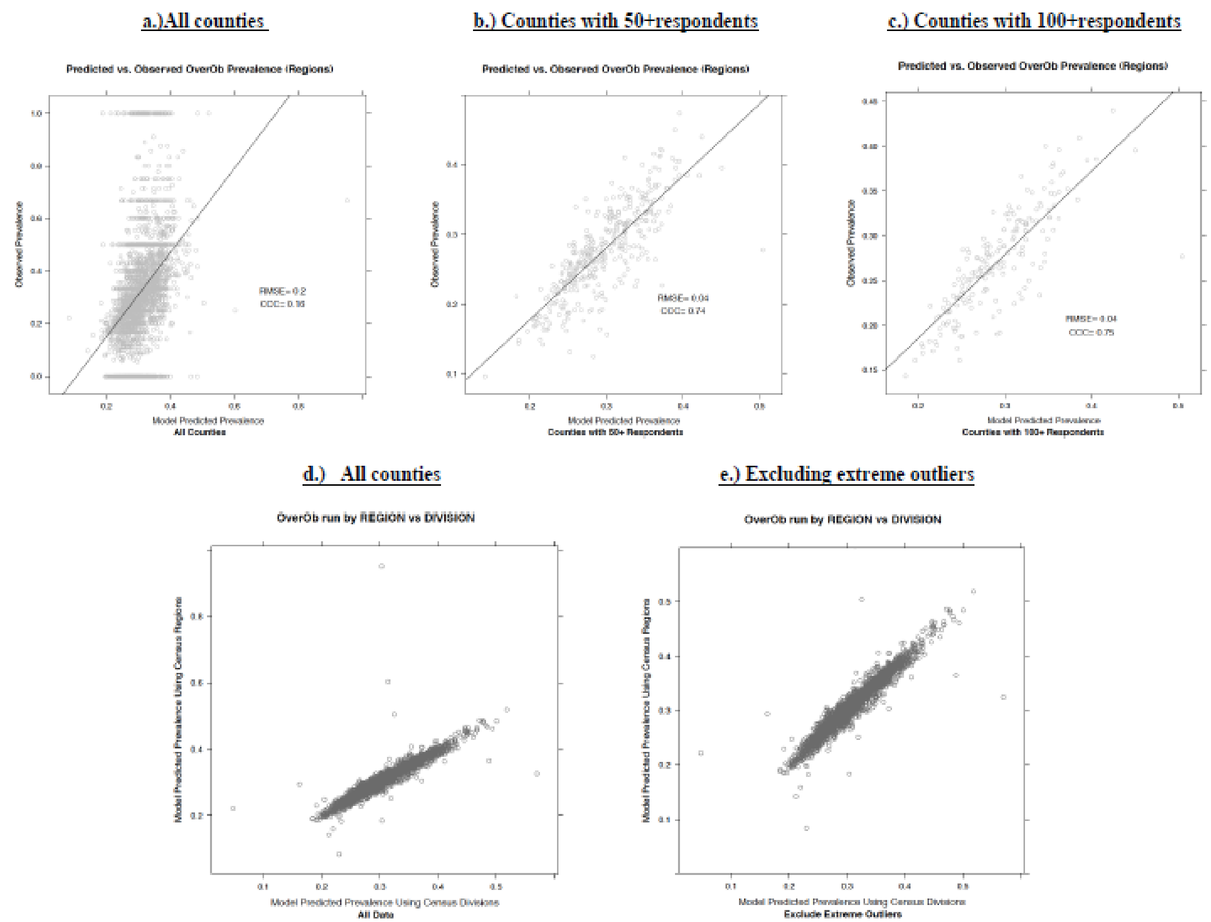


Figure 11. Sensitivity results for model-based *overweight alone* prevalence estimates among US children (10-17 years) for all US counties. [Data source: 2003 and 2007 NSCH]

Scatterplots of observed design-based vs. predicted (figures a-c) model-based *overweight alone* prevalence estimates and by region and division models (figures d and e) among US children (10-17 years) for all US counties modeled by Census region. [Data source: 2003 and 2007 NSCH]

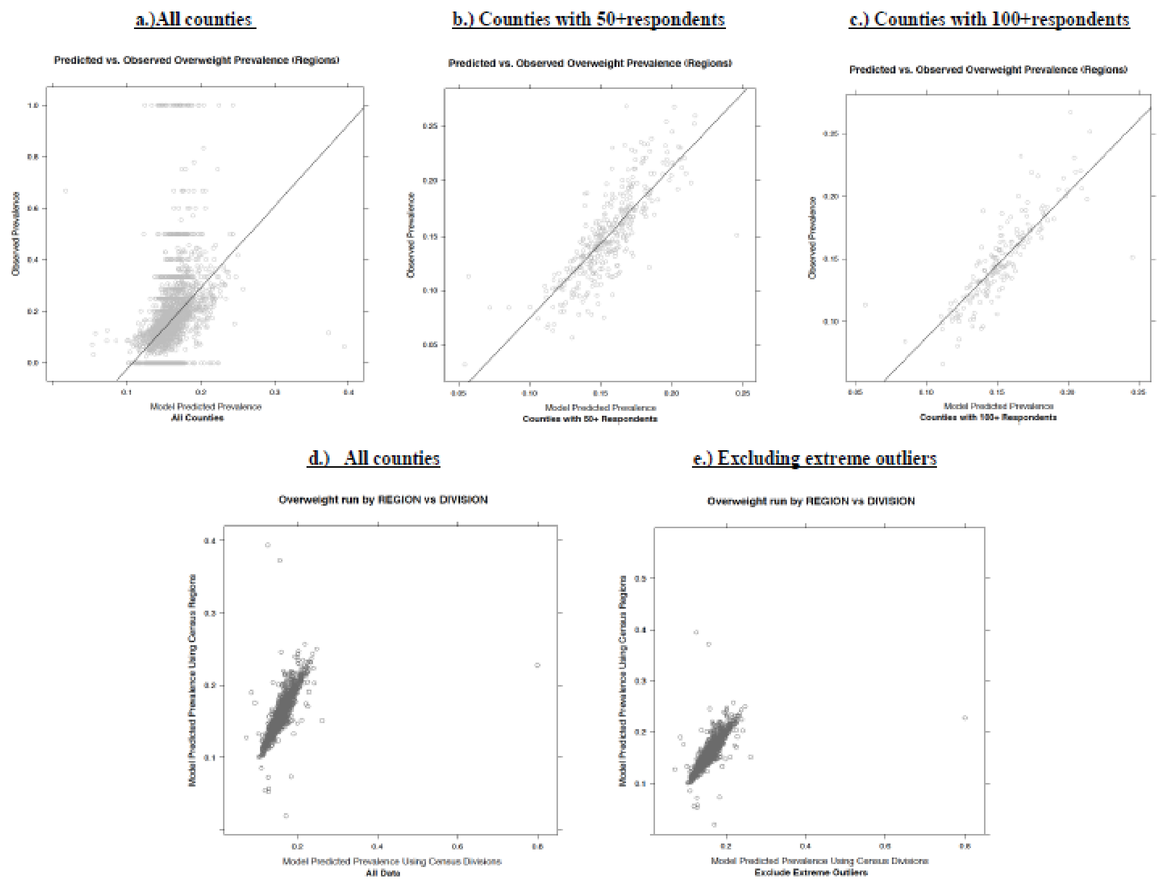
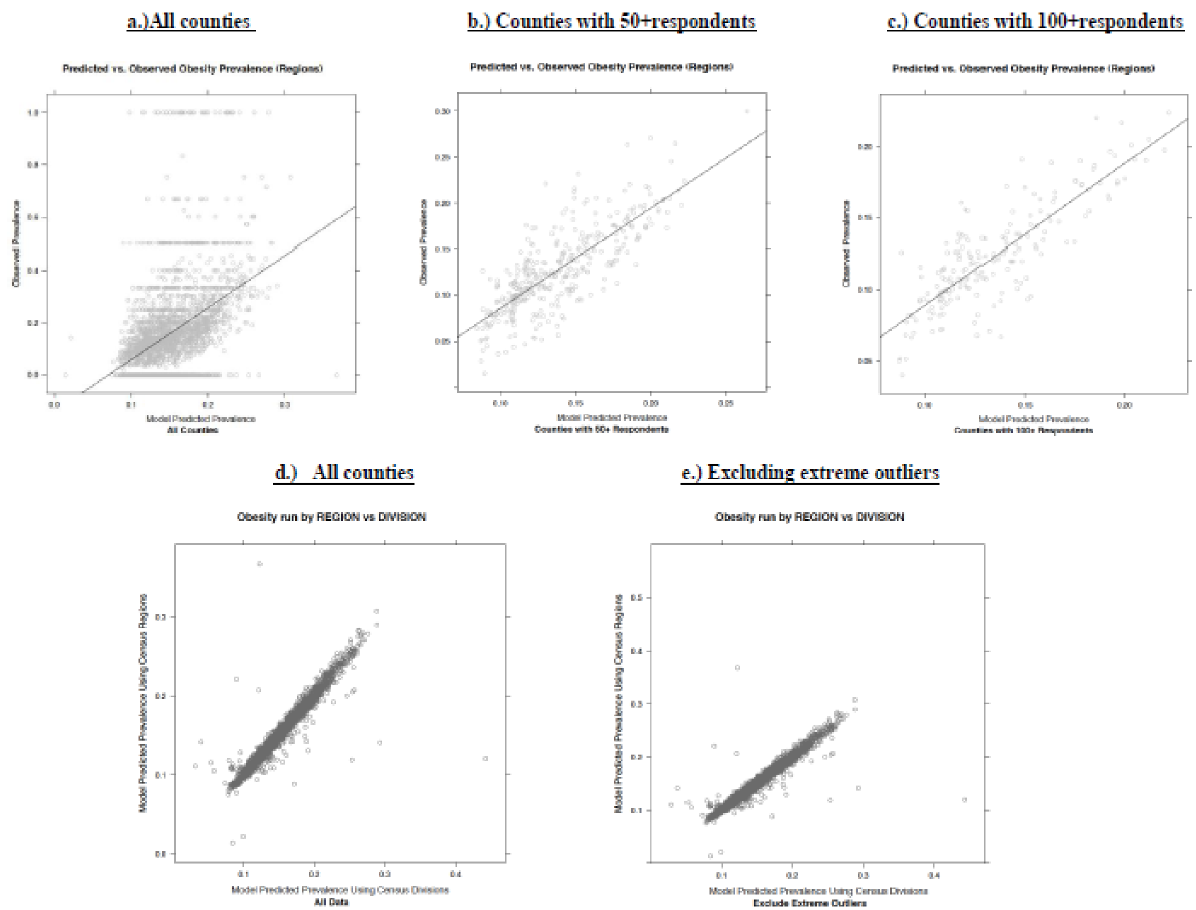


Figure 12. Sensitivity results for model-based *obesity alone* prevalence estimates among US children (10-17 years) for all US counties. [Data source: 2003 and 2007 NSCH]

Scatterplots of observed design-based vs. predicted (figures a-c) model-based *obesity alone* prevalence estimates and by region and division models (figures d and e) among US children (10-17 years) for all US counties modeled by Census region. [Data source: 2003 and 2007 NSCH]



CHAPTER 3: Summary, Public Health Implications, Possible Future Directions

The objective of this study was to generate county-level estimates for overweight and obesity prevalence among US adolescents using a Bayesian small area estimation approach with 2003 and 2007 National Survey of Children's Health (NSCH) data. These results were used to identify geographic disparities of childhood excess weight that may exist across the nation and within states. The geographic variation of low and high burden counties may help to identify where intervention has been successful and to better allocate resources. These predicted estimates were then analyzed with potential ecologic correlates to identify how obesogenic environments may be influencing these disparities. These small area estimation and ecologic analysis results may inform health policy, private and public sectors, all levels (local, state, and national) of government, public health interventions and future academic research.

Geographic disparities of childhood obesity prevalence

The model-based prevalence estimates are similar to those found in other studies using NSCH data and other national survey data with 30.7% of US adolescents being overweight or obese (Table 2).[3,57] The geographic pattern is similar to that seen among the adult population with higher prevalence in the Mississippi Delta region, the Appalachian counties of Tennessee, Kentucky, and West Virginia, the coastal rural regions of North and South Carolina, tribal lands in the western US, along the Texas-Mexico border and northwestern Alaska (Figure 1). The prevalence for *overweight alone* among adolescents is less apparent when compared to the geographic variability of *obesity alone* prevalence. The South region and East South Central division had the highest prevalence for all three outcomes (Table 2). Yet Alabama and Alaska have a majority of counties with a high prevalence of overweight adolescents (Figure 2).

Counties that were above and below the national mean (refer to Methods section of Chapter 2.1 for definition) did follow similar patterns to *overweight including obesity* prevalence yet areas of low and high burden were apparent. Those counties predicted to be below the national average were located primarily in the West and high prevalence counties were found primarily in Mississippi (Figure 4). For *obesity alone*, the West shared a low burden of childhood obesity with a few New England states and southern Alaska. Only rural areas of Mississippi and Alabama were identified as counties with an obesity prevalence that confidently surpassed the national average (Figure 4).

Importance of small area estimates

These county-level estimates were created to identify the variation of the burden of overweight and obesity prevalence among US children and adolescents within states. There are no published studies to date that have examined high body mass among US children nationwide at the county scale. With publicly available data and advancements in spatial modeling, creating model-based estimates is less cumbersome than it has ever been. There are myriad implications when translating surveillance data into geographic depictions of population health.

This method provides small-area estimates that identify high-risk areas of overweight and obesity prevalence among U.S. adolescents, which may influence individual and population-level health through proper allocation of local and federal resources. It is important to identify the areas of greatest burden so that policy makers can determine the appropriate intervention and prevention services needed. Intervention programs are usually implemented at the local and county level and concentrating these efforts in high burden counties could prove to be an effective means to curbing and reducing the overweight and obesity prevalence among children. In addition to guiding health policy, these data can inform communities to encourage change within their own homes and neighborhoods. There is a potential impact on medical education for all health providers. These results may facilitate a prioritization of topics by region, state and community based on the local burden of overweight and obesity prevalence among the children of that area. These results can inform already practicing local health care providers and national clinical leaders with local-level information needed to combat obesity in high burden areas. These area-based research results allow for a better understanding of the county risk profile, which can be integrated with basic science, clinical and behavioral information.

Obesogenic environment correlates of county-level childhood obesity

Counties burdened with a high prevalence of childhood obesity may vary by demographics and the presence of obesogenic environments. Identifying relevant county-level risk factors allows for a customization of local and state response to the unique challenges for each community. Most indicators worsen with increasing *overweight including obesity* prevalence suggesting poor food assistance, reduced food access, poor socioeconomic conditions and poor built environment amenities (Table 5). Adolescents were more likely to be overweight or obese in counties with high rates of violent crime, child poverty and unemployment. Urban and suburban counties were more likely to have increased excess weight prevalence when compared to rural counties. Counties in the South were most at risk for high *overweight including obesity* prevalence. High *obesity alone* prevalence counties were associated with more indicators of poor socioeconomic conditions including income inequality. High levels of food assistance both in the home and school environment were also associated with obese counties. An increased risk of childhood overweight and obesity among counties with high proportions of black and Hispanic populations may suggest residential segregation effects. Yet differences arise when *overweight alone* prevalence and *obesity alone* prevalence were assessed separately. Poor adult health, high unemployment rates and Hispanic residential segregation were associated with higher *overweight including obese* prevalence. Counties with a higher *Obesity alone* prevalence were associated with increased food assistance and poor socioeconomic indicators as well as more defined geographic patterns such as high *Obesity alone* prevalence in the South and non-rural (suburban and urban) counties. Therefore, local-level intervention may need to consider whether they are targeting a population that has a high childhood overweight or obese prevalence or both.

Understandably, the risk for adverse health outcomes and comorbidities is greatest among the obese but the overweight may require a different strategy to prevent a transition towards obesity.

Several patterns emerge when limiting the counties of focus to those that were above and below the national average possibly highlighting those contextual county characteristics, which may contribute to obesogenic environments. There is disproportionately higher adolescent obesity prevalence as the county proportion of non-Hispanic black population increases. The number of kids receiving school food assistance is nearly doubled and these counties receive nearly six times the national average for WIC and SNAP assistance benefits. Higher median household income, lower rates of childhood poverty and unemployment and better adult health were associated with counties that fall below the national childhood overweight and obesity prevalence.

Each high obesity prevalence county may be associated with a unique combination of physical, economic, sociocultural and political environments. Policy and community response can identify the unique risk profile of overweight and obese counties and target intervention and prevention strategies and resources accordingly. This may maximize the use of existing resources and proper allocation of funds when modifying the specific obesogenic mechanisms of high-risk counties.

Childhood obesity as a national priority

Childhood obesity has been declared a public health priority worldwide by WHO and in the United States by CDC.[34,218] As outlined by the CDC's director, contextual changes are need to create healthier environments which include improved community planning, food access, transportation and taxing sugar-sweetened beverages.[219] There are many policy-based initiatives occurring at the federal level. The health reform law, the Patient Protection and Affordable Care Act of 2010, has a component to address the obesity epidemic. This includes a number of prevention and wellness provisions such as obesity screening of adults and children, demonstration project funding, nutrient disclosure in chain restaurants and on vending snack items, and extending health insurance coverage to millions of uninsured Americans.[220] The National Health Survey in 2006 indicated that 9.3% of children under the age of 18 did not have health insurance. A White House Task Force on Childhood Obesity created under President Obama has issued a national strategy focused on obesity prevention. This initiative requires participation from every agency in the federal government to reduce the rate of childhood obesity from 14% to 7% by 2030.[4] Also launched concurrently with the Obama administration, the "Let's Move" initiative has charged itself with the well-intentioned goal of solving childhood obesity within a generation. Efforts to achieve this goal include measuring body mass index at every well-child visit and physician-promoted health behaviors to prevent obesity.[221,222]

Addressing obesity-promoting behaviors

Strategies to prevent childhood obesity include decreasing consumption of high energy-dense foods and sugar-sweetened beverages, decreasing time spent watching television, modification of food marketing focused to children, and increasing consumption of fruits and vegetables. There is a long list of school-based intervention studies investigating the most successful path to intervening and preventing childhood obesity. A main objective of these programs is to target modifiable health behaviors pertaining to physical activity and nutrition focusing on a reduction of television screen time, carbonated (sugar-sweetened) beverage consumption and increasing physical exercise in schools.[223,224] School-based interventions specifically on food quality is commonly addressed in current research. The number of states with meal nutrition standards stricter than U.S. Department of Agriculture (USDA) requirements and competitive food restriction enforcement has increased in recent years.[4]

In addition to an imbalance in physical output and caloric intake, behavioral and environmental factors are significant contributing factors to becoming overweight.[37] In view of previous education efforts not being profoundly successful, an overhaul in public health initiatives regarding health education, promotion and disease prevention is essential in modifying poor health behaviors. Adjusting the focus of previous health education to include the entire family, so that educating the parent will trickle down to their children and vice versa. Following the aforementioned CDC recommendations, physical exercise should be strongly encouraged while limiting sedentary lifestyle. This can be implemented through supporting safe communities in an effort to encourage physical activity as well as alternative modes of transportation to work and school such as biking or walking.[37] Current programs focused on improving neighborhood safety and access to sidewalks for children include Promote Safe Routes to School (SRTS) and Complete Streets.[88]

Targeting food environments

There is an opportunity to modify and improve the food environment for US children both at the micro and macro-levels. Parental nutrition education and diet improvement can elicit change at home. Modifying school food offerings such as healthier lunch options and encouraging breakfast may improve the overall diet for school-aged children. With each school age child obtaining food from school about 190 days a year, there is an opportunity to improve the quality of cafeteria food, promote food education, and demand properly trained food professionals.[225] Community-based public health interventions may promote school gardens, farm-to-table, and weekly farmer's markets. Food access may be improved by offering incentives to food stores to move into food deserts or limiting the number of junk food and sugar-sweetened beverages children can purchase in convenience stores. Health policy has the opportunity to modify food pricing by focusing on economic sustainability to decrease the price of fresh produce per calorie to be more comparable with processed, energy-dense foods.

Prevention strategies should be considered at all developmental stages throughout childhood beginning in pregnancy.[85] Some examples may include promoting exclusive breastfeeding and avoidance of early juice consumption, family meal time and physical activities, and better food choices available in and surrounding school. Interdisciplinary collaboration should be encouraged with other sectors including housing development and city planning whose abilities and expertise combined can directly and indirectly improve a community's health through modifications of the food and built environments.

How obesogenic environments promote childhood obesity using the ANGELO framework

The ANGELO framework is a tool used to conceptualize how environments may influence obesity.[226,227] Within this framework, there are two scales and four types of environments that may contribute to the rise of excess weight. There is an individual-level, smaller ("micro-environment") community-based environment including the home/school, workplace and neighborhood. The broader ("macro-environment") reaching scale is at the population level involving food subsidies and health policy. The four types of environments include physical, economic, sociocultural, and political. A majority of obesity literature has focused on physical and economic environment types with less research on the role of sociocultural and political environments.[158]

There have been many environmental and policy interventions which have been successful in modifying obesogenic environments. These include improvements to the physical environments such as improving access to green space and healthy foods, addressing a lack of amenities and improving transportation. Economic solutions including reducing the cost of fresh produce, addressing financial priorities of the working poor, and enhancing food assistance programs. Increasing portion sizes, food marketing, perceiving neighborhood safety and racial/ethnic composition all influence a community's sociocultural environment. Lastly, policy dictates the focus of macro processes contributing to obesogenic environments such as health policy, national food production and presence of vending machines in schools. An indirect effect of policy modifying these environments is behavior change to promote health. As indicated in Chapter 1, creating safer neighborhoods may increase physical activity levels.

Interventions to physical environment

Differences in access to sidewalks, neighborhood safety, and recreational venues that may exist between rural and urban communities could provide an opportunity to target each unique population. It has been suggested that intervention among rural children should be more focused on physical activity interventions; whereas nutritional education programs may be most instrumental among urban children.[124] Additional barriers that exist for rural residents include fewer health education programs and less access to nutritionists which should be considered when choosing an appropriate intervention.[228]

Another policy-driven initiative focuses on improving the community food environment with better access to nutritionally healthy foods. A 2009 estimate by the USDA reveals that as many as 23.5 million adults and children across the nation may live in a 'food desert' where residents rely mostly on packaged, highly processed foods and fast food restaurants.[229] The Fresh Food Financing Initiative (FFFI), which follows the framework of The Food Trust, is a public-private partnership in Pennsylvania focused on improving access to healthier food choices with the potential goal that improved eating habits may decrease obesity. By means of loans and grants, FFFI has committed nearly $60 million to fund 78 fresh food supply stores serving over 500,000 residents.[230,231] Mobile grocers have been used to improve access to healthier food options in 'food desert' areas including Indian reservations in New Mexico and the Bronx in New York.[232]

Interventions to economic environment

In an effort to improve the diets of Americans, food assistance programs, pilots include those seen in Massachusetts and California, may lead to increased fresh produce purchasing and consumption. As part of an initiative within the USDA's 2008 Farm Bill, the beneficiaries of Supplemental Nutritional Assistance Program (SNAP) in Massachusetts are receiving 30 cents off every dollar spent on fresh produce.[233,234] Similarly, the 'Healthy Purchase' pilot program participants in California are subsidized a portion of each dollar spent on produce.[234,235] Another pilot program, which partners the CDC with the International City/County Management Association, is measuring the effects of 24 strategies to reduce obesity through the efforts of state health departments in Minnesota and Massachusetts.[229]

Interventions to sociocultural environment

With each child viewing an average of 15 food commercials per day, there is an opportunity to use food marketing as a tool in the prevention of childhood obesity. Evidence indicates that food marketing strongly influences a child's preference towards advertised food, which could be focused toward healthier options. However, this industry does involve many obstacles, which prevent any immediate changes. These barriers include social attitudes and opinions, free market and protected speech, and uncertain regulatory authorities responsible for food marketing.[236]

There is a need to reduce obesity-related stigma through changing the social context of childhood overweight and obesity. It is unclear what this campaign would look like but somewhere between obesity being okay and detestable. Possibly, placing a less negative and repelling spin on being overweight but highlight the concerns about being obese and extremely obese. It is assumed that the constant barrage of being overweight as ugly and undesired may cause children and adults to shut down and ignore the message. Need to somehow modify the social norms surrounding a sedentary and poor food choice lifestyle. Focus on the concept that healthy bodies come in all shapes and sizes rather than negatively market fat bodies.

Interventions to political environment

To further promote a sense of community in our increasingly detached nation, we need to encourage an organization for change. An interdisplinary approach to community planning should be encouraged to achieve functional, healthy neighborhoods and communities. This involves promoting the purchase of local and seasonal foods as well as offering incentives for farming and gardening to provide for personal and/or community use. Some innovative ideas to discourage nutrition poor, energy dense food consumption may be to place restrictions on the geographical locations and density of fast food establishments. Local governments can incentivize grocery stores and supermarkets to establish in low-income areas, which are disproportionately affected by obesity possibly as a consequence of creating 'food deserts'. Offer incentives to businesses of healthier and smarter food choices to replace fast food restaurant options. Implement limitations on the amount of snack food and high-sugar beverages that children can purchase at school and in convenience stores. Following CDC recommendations, supporting programs and policies to encourage physical activity with better access to nutritionally important foods, and improving the built environment should focus on making communities places where children can live, walk and play.[34]

The American economy is a capitalist one founded on the idea that every individual has the freedom to make their own consumption choices—purchase and eat whatever one wants.[237] There are many barriers for policymakers to intervene because it may be interpreted as loss of personal freedom. Therefore, most potential policy solutions are focused on adjusting or improving the obesogenic environment such as limiting the sale of poor food choices, taxing sugar-sweetened beverages, and/or restricting youth-targeted advertising rather than population-based changes such as redistributing wealth to decrease poverty.[238]

Where do we go now?

Limitations in current research include the lack of a nationally representative sample of urban and rural children obtained simultaneously to better understand health behavior differences in the rates of obesity among rural and urban children. Future data collection surveys such as the 2011 NSCH and The National Children's Study (NCS) may attempt to fill this knowledge gap. The 2011 NSCH began February 2011 and is scheduled for completion in March 2012[239] while the NSC has only recently completed piloting of the recruitment phase of a proposed 21-year longitudinal study.[240] The NCS data set will include several social and environmental variables from preconception through to late adolescence that may lend information to better understand obesity trends among children that may identify potential obesogenic environments.[240]

Alternatives to measure body mass should be considered. Standard measurement using BMI evaluates adiposity indirectly; it measures excess body fat relative to height rather than adiposity, which is more appropriate for obesity measurements.[241] Correlation of BMI and adiposity in children varies by age, sex, and race which highlights that current BMI measurements may not be ideal when evaluating obesity among children.[1,241] Future research may identify specific cutoff values that better predict health risk by sex, age and race-ethnicity among children. There is a need for a widely accepted and standardized definition worldwide for overweight and obesity among children and adolescents.

The lack of information explaining how much genetics plays a role in one's propensity for obesity promotes an epigenetic study. Further research is needed to better understand the influence of social determinants of health compared to genetic risk among overweight and obese adolescents. This may elucidate the pathways for why maternal obesity and diabetes is such a strong predictor of childhood obesity. Larger sample sizes would allow for more racial-ethnic subgroup analyses, which may identify rural/urban differences in breastfeeding practices, cultural diet and other predictive contextual characteristics.

Local-level surveillance should be employed and/or enhanced to achieve more precise estimates of the burden of childhood obesity. Place-based research should be used routinely to better understand the factors that create obesogenic environments at the local level. Each community has its own recipe of social, environmental and demographics differences which need to be identified and should be addressed when developing health education and nutrition programs. Future research that would contribute to this topic would include a multi-level approach to examine indicators of the social, economic and physical environments at the individual and county level. A principal component analysis using these model-based prevalence estimates and contextual variables may elucidate a childhood obesity index that acts to predict overweight and obesity prevalence among US adolescents at the county level.

Conclusion

Individual-level behaviors such as poor diet and reduced physical activity have been consistently linked to increased obesity risk but the mechanisms that create obesogenic environments must also be addressed. Overweight adolescents and their families cannot be the sole responsible parties for making lifestyle and behavior adjustments but rather collaborative public and private involvement is required to facilitate a successful and permanent change. There is a need to shift intervention and improvement focus towards population-level and structural factors that are often out of the control of individuals rather than blame the victim. Childhood obesity is of huge public health significance with everyone being affected personally, socially and/or economically. Understanding childhood obesity trends at the local level is vital in developing tailored intervention responses and policy to reduce and prevent excess weight among children. This study has contributed to the body of literature of childhood obesity in a unique way and highlighted possible policy and community-based solutions to improve the childhood obesity burden in America.

APPENDIX

TABLES

Table A1. Model-based overweight and obesity prevalence estimates for children aged 10-17 years for the ten (10) lowest and highest counties per outcome of interest (Data source: 2003 and 2007 NSCH)

	Overweight including obesity			Overweight alone			Obesity alone		
	Mean	Lower credible interval	Upper credible interval	Mean	Lower credible interval	Upper credible interval	Mean	Lower credible interval	Upper credible interval
Highest 10 Counties									
1	60.3%	43.4%	82.5%	39.4%	23.2%	59.2%	36.7%	27.6%	47.3%
2	51.9%	41.2%	65.2%	37.3%	29.8%	44.0%	30.7%	18.3%	47.8%
3	50.4%	38.0%	63.6%	25.7%	16.1%	38.9%	29.0%	19.4%	42.1%
4	48.7%	38.9%	60.4%	25.0%	17.3%	35.6%	28.3%	16.1%	45.1%
5	48.5%	38.3%	62.3%	24.7%	15.7%	36.8%	28.2%	17.1%	45.6%
6	48.4%	38.2%	59.9%	24.6%	20.0%	29.1%	27.9%	17.7%	42.0%
7	48.3%	37.5%	60.6%	24.4%	16.3%	36.0%	27.9%	16.8%	44.1%
8	47.9%	38.8%	58.3%	24.3%	12.5%	45.4%	27.7%	17.1%	42.3%
9	47.3%	38.0%	59.2%	24.3%	12.6%	41.7%	27.6%	16.4%	45.7%
10	46.6%	37.7%	57.1%	24.0%	13.1%	42.7%	27.5%	16.9%	42.9%
Lowest 10 Counties									
1	8.4%	5.4%	12.5%	1.9%	1.6%	2.3%	1.4%	0.9%	1.9%
2	14.1%	8.5%	21.8%	5.3%	2.8%	9.0%	2.1%	1.5%	3.3%
3	15.8%	10.9%	22.7%	5.4%	2.2%	10.2%	7.5%	5.1%	10.4%
4	18.2%	11.5%	27.7%	5.7%	3.3%	9.2%	7.7%	5.2%	11.0%
5	18.4%	13.4%	25.7%	7.2%	3.3%	13.3%	7.9%	5.4%	11.1%
6	18.5%	13.6%	24.6%	7.3%	3.9%	12.6%	8.1%	5.5%	11.6%
7	18.6%	13.1%	24.7%	8.5%	6.0%	11.7%	8.2%	4.8%	12.4%
8	18.7%	12.7%	25.7%	10.0%	6.1%	14.8%	8.3%	5.4%	12.0%
9	18.9%	12.4%	27.7%	10.1%	5.6%	17.0%	8.3%	5.5%	11.8%
10	19.0%	12.7%	27.9%	10.2%	5.2%	16.9%	8.4%	5.2%	12.7%

Table A2. Basic descriptive statistics of NSCH data for 2003, 2007 and combined 2003 and 2007 (n, %) by Census-derived region for US children aged 10-17 years.

	Northeast						Midwest					
	2003		2007		All		2003		2007		All	
Total respondents	8333		7971		16304		11049		10783		21832	
Overweight including obesity	2385	28.6%	2187	27.4%	4572	28.0%	3001	27.2%	3036	28.2%	6037	27.7%
Overweight alone	1306	15.7%	1186	14.9%	2492	15.3%	1577	14.3%	1611	14.9%	3188	14.6%
Obesity alone	1079	12.9%	1001	12.6%	2080	12.8%	1424	12.9%	1425	13.2%	2849	13.0%
Age												
10-14 years	4993	59.9%	4471	56.1%	9464	58.0%	6346	57.4%	6061	56.2%	12407	56.8%
15-17 years	3340	40.1%	3500	43.9%	6840	42.0%	4703	42.6%	4722	43.8%	9425	43.2%
Race-ethnicity												
Non-Hispanic White	6748	81.0%	6146	77.1%	12894	79.1%	9249	83.7%	8637	80.1%	17886	81.9%
All other races	1585	19.0%	1825	22.9%	3410	20.9%	1800	16.3%	2146	19.9%	3946	18.1%
Sex												
Male	4326	51.9%	4198	52.7%	8524	52.3%	5750	52.0%	5598	51.9%	11348	52.0%
Female	4007	48.1%	3773	47.3%	7780	47.7%	5299	48.0%	5185	48.1%	10484	48.0%

	South						West					
	2003		2007		All		2003		2007		All	
Total respondents	15605		14527		30132		10846		10820		21666	
Overweight including obesity	5070	32.5%	4752	32.7%	9822	32.6%	2826	26.1%	2819	26.1%	5645	26.1%
Overweight alone	2534	16.2%	2351	16.2%	4885	16.2%	1569	14.5%	1606	14.8%	3175	14.7%
Obesity alone	2536	16.3%	2401	16.5%	4937	16.4%	1257	11.6%	1213	11.2%	2470	11.4%
Age												
10-14 years	9286	59.5%	8307	57.2%	17593	58.4%	6368	58.7%	6030	55.7%	12398	57.2%
15-17 years	6319	40.5%	6220	42.8%	12539	41.6%	4478	41.3%	4790	44.3%	9268	42.8%
Race-ethnicity												
Non-Hispanic White	10462	67.0%	9274	63.8%	19736	65.5%	7254	66.9%	6998	64.7%	14252	65.8%
All other races	5143	33.0%	5253	36.2%	10396	34.5%	3592	33.1%	3822	35.3%	7414	34.2%
Sex												
Male	7949	50.9%	7608	52.4%	15557	51.6%	5616	51.8%	5586	51.6%	11202	51.7%
Female	7656	49.1%	6919	47.6%	14575	48.4%	5230	48.2%	5234	48.4%	10464	48.3%

Table A3. Basic descriptive statistics of NSCH data for 2003, 2007 and combined 2003 and 2007 (n, %) by Census-derived division for US children aged 10-17 years.

	New England						Middle Atlantic						East North Central					
	2003		2007		All		2003		2007		All		2003		2007		All	
Total respondents	5519		5404		10923		2814		2567		5381		4661		4527		9188	
Overweight including obesity	1530	27.7%	1398	25.9%	2928	26.8%	855	30.4%	789	30.7%	1644	30.6%	1374	29.5%	1356	30.0%	2730	29.7%
Overweight alone	847	15.3%	780	14.4%	1627	14.9%	459	16.3%	406	15.8%	865	16.1%	708	15.2%	675	14.9%	1383	15.1%
Obesity alone	683	12.4%	618	11.4%	1301	11.9%	396	14.1%	383	14.9%	779	14.5%	666	14.3%	681	15.0%	1347	14.7%
Age																		
10-14 years	3261	59.1%	2997	55.5%	6258	57.3%	1732	61.5%	1474	57.4%	3206	59.6%	2702	58.0%	2598	57.4%	5300	57.7%
15-17 years	2258	40.9%	2407	44.5%	4665	42.7%	1082	38.5%	1093	42.6%	2175	40.4%	1959	42.0%	1929	42.6%	3888	42.3%
Race-ethnicity																		
Non-Hispanic White	4724	85.6%	4618	85.5%	9342	85.5%	2024	71.9%	1528	59.5%	3552	66.0%	3707	79.5%	3265	72.1%	6972	75.9%
All other races	795	14.4%	786	14.5%	1581	14.5%	790	28.1%	1039	40.5%	1829	34.0%	954	20.5%	1262	27.9%	2216	24.1%
Sex																		
Male	2869	52.0%	2835	52.5%	5704	52.2%	1457	51.8%	1363	53.1%	2820	52.4%	2413	51.8%	2323	51.3%	4736	51.5%
Female	2650	48.0%	2569	47.5%	5219	47.8%	1357	48.2%	1204	46.9%	2561	47.6%	2248	48.2%	2204	48.7%	4452	48.5%

	South Atlantic						East South Central						West South Central					
	2003		2007		All		2003		2007		All		2003		2007		All	
Total respondents	8215		7585		15800		3736		3573		7309		3654		3369		7023	
Overweight including obesity	2607	31.7%	2355	31.0%	4962	31.4%	1310	35.1%	1312	36.7%	2622	35.9%	1153	31.6%	1085	32.2%	2238	31.9%
Overweight alone	1319	16.1%	1201	15.8%	2520	15.9%	636	17.0%	628	17.6%	1264	17.3%	579	15.8%	522	15.5%	1101	15.7%
Obesity alone	1288	15.7%	1154	15.2%	2442	15.5%	674	18.0%	684	19.1%	1358	18.6%	574	15.7%	563	16.7%	1137	16.2%
Age																		
10-14 years	4909	59.8%	4336	57.2%	9245	58.5%	2250	60.2%	2014	56.4%	4264	58.3%	2127	58.2%	1957	58.1%	4084	58.2%
15-17 years	3306	40.2%	3249	42.8%	6555	41.5%	1486	39.8%	1559	43.6%	3045	41.7%	1527	41.8%	1412	41.9%	2939	41.8%
Race-ethnicity																		
Non-Hispanic White	5297	64.5%	4694	61.9%	9991	63.2%	2775	74.3%	2561	71.7%	5336	73.0%	2390	65.4%	2019	59.9%	4409	62.8%
All other races	2918	35.5%	2891	38.1%	5809	36.8%	961	25.7%	1012	28.3%	1973	27.0%	1264	34.6%	1350	40.1%	2614	37.2%
Sex																		
Male	4179	50.9%	3982	52.5%	8161	51.7%	1923	51.5%	1876	52.5%	3799	52.0%	1847	50.5%	1750	51.9%	3597	51.2%
Female	4036	49.1%	3603	47.5%	7639	48.3%	1813	48.5%	1697	47.5%	3510	48.0%	1807	49.5%	1619	48.1%	3426	48.8%

	West North Central						Mountain						Pacific					
	2003		2007		All		2003		2007		All		2003		2007		All	
Total respondents	6388		6256		12644		6452		6703		13155		4394		4117		8511	
Overweight including obesity	1627	25.5%	1680	26.9%	3307	26.2%	1601	24.8%	1677	25.0%	3278	24.9%	1225	27.9%	1142	27.7%	2367	27.8%
Overweight alone	869	13.6%	936	15.0%	1805	14.3%	893	13.8%	937	14.0%	1830	13.9%	676	15.4%	669	16.2%	1345	15.8%
Obesity alone	758	11.9%	744	11.9%	1502	11.9%	708	11.0%	740	11.0%	1448	11.0%	549	12.5%	473	11.5%	1022	12.0%
Age																		
10-14 years	3644	57.0%	3463	55.4%	7107	56.2%	3729	57.8%	3717	55.5%	7446	56.6%	2639	60.1%	2313	56.2%	4952	58.2%
15-17 years	2744	43.0%	2793	44.6%	5537	43.8%	2723	42.2%	2986	44.5%	5709	43.4%	1755	39.9%	1804	43.8%	3559	41.8%
Race-ethnicity																		
Non-Hispanic White	5542	86.8%	5372	85.9%	10914	86.3%	4678	72.5%	4794	71.5%	9472	72.0%	2576	58.6%	2204	53.5%	4780	56.2%
All other races	846	13.2%	884	14.1%	1730	13.7%	1774	27.5%	1909	28.5%	3683	28.0%	1818	41.4%	1913	46.5%	3731	43.8%
Sex																		
Male	3337	52.2%	3275	52.3%	6612	52.3%	3331	51.6%	3516	52.5%	6847	52.0%	2285	52.0%	2070	50.3%	4355	51.2%
Female	3051	47.8%	2981	47.7%	6032	47.7%	3121	48.4%	3187	47.5%	6308	48.0%	2109	48.0%	2047	49.7%	4156	48.8%

Table A4. Correlation of each covariate (continuous, standardized, and quintiled) with each overweight and obesity outcome.

	CONTINUOUS COVARIATES						STANDARDIZED COVARIATES						QUINTILES COVARIATES					
	Overweight including obesity		Overweight alone		Obesity alone		Overweight including obesity		Overweight alone		Obesity alone		Overweight including obesity		Overweight alone		Obesity alone	
County-level covariates	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value
Physical Activity																		
Proportion of Workers that Walk to Work (n=3138)[a]	-0.19885	<.0001	0.00241	0.8926	-0.28156	<.0001	-0.19885	<.0001	0.00241	0.8926	-0.28156	<.0001	-0.35034	<.0001	-0.14312	<.0001	-0.40584	<.0001
Recreation & fitness facilities/ 1,000 pop, 2008 (n=3140)[b]	-0.2021	<.0001	-0.10277	<.0001	-0.21148	<.0001	-0.2021	<.0001	-0.10277	<.0001	-0.21148	<.0001	-0.18551	<.0001	-0.10206	<.0001	-0.19612	<.0001
Neighborhood Safety																		
Violent crime rate (per 100,000 county population)[c]	0.35883	<.0001	0.24734	<.0001	0.32091	<.0001	0.35883	<.0001	0.24734	<.0001	0.32091	<.0001	0.35807	<.0001	0.21657	<.0001	0.34654	<.0001
Food environment																		
% Low income & > 1 mi to store, 2006 (n=3108)[d]	0.2796	<.0001	0.18238	<.0001	0.29765	<.0001	0.2796	<.0001	0.18238	<.0001	0.29765	<.0001	0.27174	<.0001	0.17571	<.0001	0.29164	<.0001
% Low income & > 10 mi to store, 2006 (n=3108)[d]	-0.16012	<.0001	-0.08408	<.0001	-0.16949	<.0001	-0.16012	<.0001	-0.08408	<.0001	-0.16949	<.0001	-0.13098	<.0001	-0.0532	0.003	-0.12964	<.0001
% Households with no car & > 1 mi to store, 2006 (n=3108)[d]	0.45346	<.0001	0.27334	<.0001	0.47407	<.0001	0.45346	<.0001	0.27334	<.0001	0.47407	<.0001	0.41142	<.0001	0.24413	<.0001	0.43603	<.0001
% Households with no car & > 10 mi to store, 2006 (n=3108)[d]	-0.03578	0.0462	-0.01751	0.3295	-0.03893	0.0301	-0.03578	0.0462	-0.01751	0.3295	-0.03893	0.0301	-0.06263	0.0005	-0.01541	0.3908	-0.06043	0.0008
Grocery stores/ 1,000 pop, 2008 (n=3140)[b]	-0.14853	<.0001	0.00232	0.8969	-0.18605	<.0001	-0.14853	<.0001	0.00232	0.8969	-0.18605	<.0001	-0.09969	<.0001	0.0073	0.6829	-0.12329	<.0001
Farmers' markets/ 1,000 pop, 2009 (n=3140)[b]	-0.17196	<.0001	-0.06868	0.0001	-0.18134	<.0001	-0.17196	<.0001	-0.06868	0.0001	-0.18134	<.0001	-0.11192	<.0001	-0.01889	0.2906	-0.1386	<.0001
Convenience stores no gas/ 1,000 pop, 2008 (n=3140)[b]	0.09559	<.0001	0.06197	0.0005	0.10255	<.0001	0.09559	<.0001	-0.01603	0.3696	0.10255	<.0001	0.18114	<.0001	0.11771	<.0001	0.18443	<.0001
Convenience stores with gas/ 1,000 pop, 2008 (n=3140)[b]	0.02409	0.1775	-0.01603	0.3696	0.06501	0.0003	0.02409	0.1775	0.06197	0.0005	0.06501	0.0003	0.08915	<.0001	0.03022	0.0907	0.13851	<.0001
Fast-food restaurants/ 1,000 pop, 2008 (n=3140)[b]	-0.31496	<.0001	-0.16763	<.0001	-0.32402	<.0001	-0.31496	<.0001	-0.16763	<.0001	-0.32402	<.0001	-0.40195	<.0001	-0.21953	<.0001	-0.41675	<.0001
Full-service restaurants/ 1,000 pop, 2008 (n=3140)[b]	-0.05507	0.002	-0.05942	0.0009	-0.05248	0.0033	-0.05507	0.002	-0.05942	0.0009	-0.05248	0.0033	-0.04297	0.0161	-0.06518	0.0003	-0.03675	0.0396
Food assistance																		
Total WIC redemptions ($1,000), 2009 (n=3005)[e]	0.06361	0.0005	0.04101	0.0247	0.03497	0.0554	0.06361	0.0005	0.04101	0.0247	0.03497	0.0554	0.2052	<.0001	0.116	<.0001	0.16736	<.0001
WIC-authorized stores/1,000 pop, 2009 (n=3005)[e]	-0.08445	<.0001	0.03589	0.0493	-0.11678	<.0001	-0.08445	<.0001	0.03589	0.0493	-0.11678	<.0001	-0.03684	0.0436	0.02714	0.1372	-0.03458	0.0582
Total SNAP benefits ($1,000), 2009 (n=3041)[f]	0.09269	<.0001	0.04896	0.007	0.0598	0.001	0.09269	<.0001	0.04896	0.007	0.0598	0.001	0.30619	<.0001	0.17797	<.0001	0.27715	<.0001
Average monthly SNAP benefits per recipient, 2009 (n=3036)[f]	-0.01154	0.5255	0.04563	0.012	-0.03899	0.0318	-0.01154	0.5255	0.04563	0.012	-0.03899	0.0318	0.08002	<.0001	0.05629	0.0019	0.07126	<.0001
SNAP-authorized stores/1,000 pop, 2009 (n=3137)[f]	0.29574	<.0001	0.22299	<.0001	0.28614	<.0001	0.29574	<.0001	0.22299	<.0001	0.28614	<.0001	0.32319	<.0001	0.21221	<.0001	0.32291	<.0001
Proportion of low-income households who are SNAP recipients, 2007 (n=3138)[f]	0.50904	<.0001	0.28244	<.0001	0.51047	<.0001	0.50904	<.0001	0.28244	<.0001	0.51047	<.0001	0.51021	<.0001	0.27812	<.0001	0.51307	<.0001
% Students free- and reduced-price lunch eligible, 2008 (n=3122)[g]	0.5868	<.0001	0.34466	<.0001	0.56089	<.0001	0.5868	<.0001	0.34466	<.0001	0.56089	<.0001	0.54949	<.0001	0.30316	<.0001	0.53861	<.0001
Adult Health																		
Adult diabetes rate, 2008 (n=3140)[h]	0.63665	<.0001	0.3577	<.0001	0.66926	<.0001	0.63665	<.0001	0.3577	<.0001	0.66926	<.0001	0.5932	<.0001	0.31846	<.0001	0.63584	<.0001
Adult obesity rate, 2008 (n=3140)[h]	0.58184	<.0001	0.41036	<.0001	0.55056	<.0001	0.58184	<.0001	0.41036	<.0001	0.55056	<.0001	0.53	<.0001	0.36563	<.0001	0.51366	<.0001
Socioeconomic																		
% Black (all ages)	0.56469	<.0001	0.351	<.0001	0.55433	<.0001	0.56469	<.0001	0.351	<.0001	0.55433	<.0001	0.49834	<.0001	0.25618	<.0001	0.51174	<.0001
% Hispanic (all ages)	0.06523	0.0003	-0.03212	0.0722	0.07909	<.0001	0.06523	0.0003	-0.03212	0.0722	0.07909	<.0001	-0.07038	<.0001	-0.12175	<.0001	-0.04867	0.0064
Median household income, 2005 (n=3140)[i]	-0.31793	<.0001	-0.17707	<.0001	-0.34333	<.0001	-0.31793	<.0001	-0.17707	<.0001	-0.34333	<.0001	-0.34089	<.0001	-0.18718	<.0001	-0.36606	<.0001
Child poverty, 2005 (n=3140)[i]	0.53794	<.0001	0.30344	<.0001	0.54777	<.0001	0.53794	<.0001	0.30344	<.0001	0.54777	<.0001	0.50822	<.0001	0.28103	<.0001	0.52066	<.0001
Gini Coefficient (n=3138)[a]	0.33582	<.0001	0.15989	<.0001	0.35411	<.0001	0.33582	<.0001	0.15989	<.0001	0.35411	<.0001	0.33908	<.0001	0.28931	<.0001	0.36279	<.0001
Unemployment rate, 2005 (n=3133)[i]	0.43826	<.0001	0.35261	<.0001	0.38916	<.0001	0.43826	<.0001	0.35261	<.0001	0.38916	<.0001	0.41862	<.0001	0.16847	<.0001	0.39935	<.0001
Rural/urban status[k]	0.07223	<.0001	0.01662	0.3522	0.05767	0.0012												

[a]American Community Survey (5-year estimate), 2005-2009

[b]U.S. Census Bureau, County Business Patterns, 2008 (Accessed via USDA's Food Environment Atlas)

[c]Uniform Crime Reporting Program Data: County-level Detailed Arrest and Offense Data, 2003 and 2007 (Accessed via Interdisciplinary Consortium of Social and Political Research)
[d]Access to Affordable and Nutritious Food--Measuring and Understanding Food Deserts and Their Consequences: Report to Congress, 2006
[e]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, Supplemental Food Programs Division, Food and Nutrition Service, USDA, 2009
[f]U.S. Census Bureau, Current Population Statistics: Program Analysis and Monitoring Branch, SNAP Benefits Redemption Division, Food and Nutrition Service, USDA, 2009
[g]Common Core of Data, National Center for Education Statistics, U.S. Department of Education, 2008
[h]Behavioral Risk F S S data from Center for Disease Control and Prevention, 2008
[i]U.S. Census Bureau, Small Area Income and Poverty Estimates, 2005
[j]Bureau of Labor Statistics, 2005
[k]NCHS Urban/Rural Classification Scheme for Counties, 2006

APPENDIX cont'd

FIGURES

Figure A1. Root-mean-square-error as a function of minimum county sample size of *overweight including obesity* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data. (Data source: 2003 and 2007 NSCH)

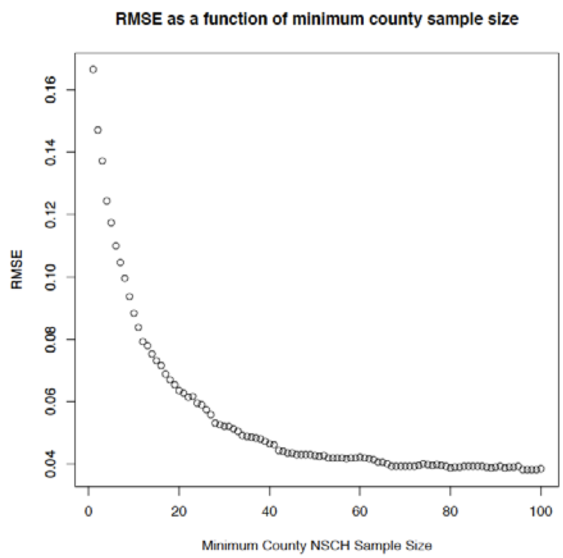


Figure A2. Concordance correlation coefficient as a function of minimum county sample size of *overweight including obesity* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data. (Data source: 2003 and 2007 NSCH)

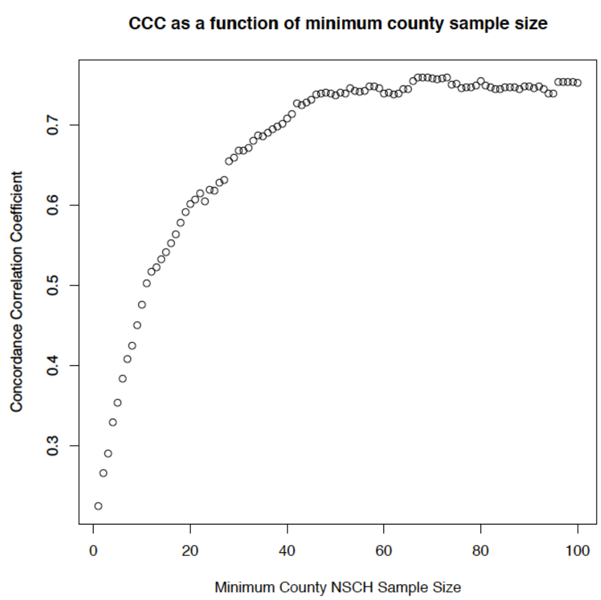


Figure A3. Model-based predicted estimates of *overweight including obesity* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data [Census division model]

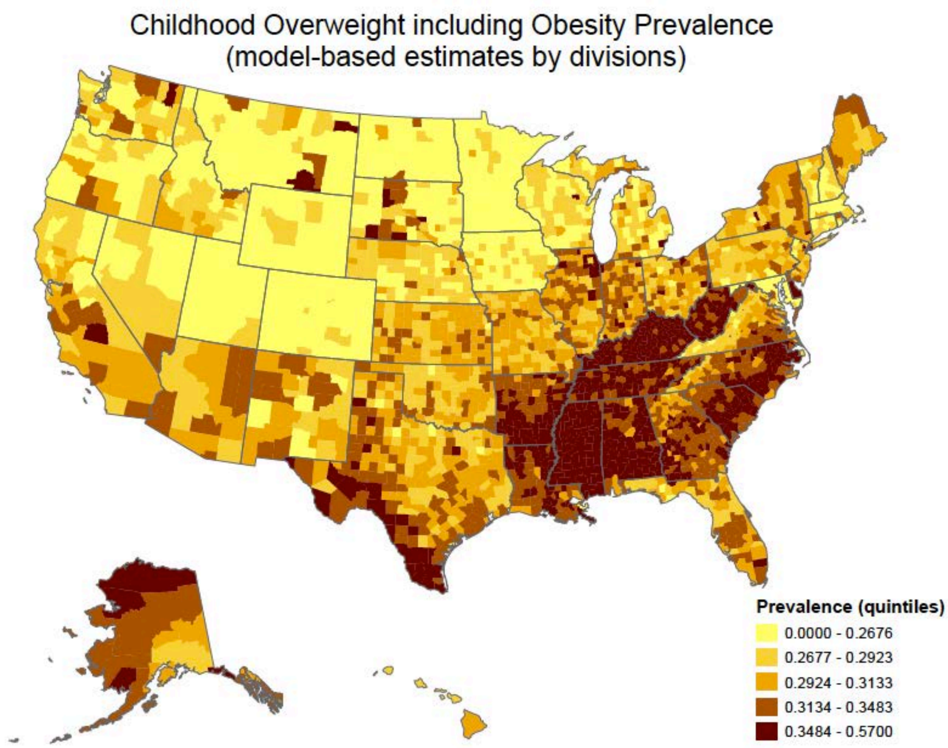


Figure A4. Root-mean-square-error as a function of minimum county sample size of *overweight alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data. (Data source: 2003 and 2007 NSCH)

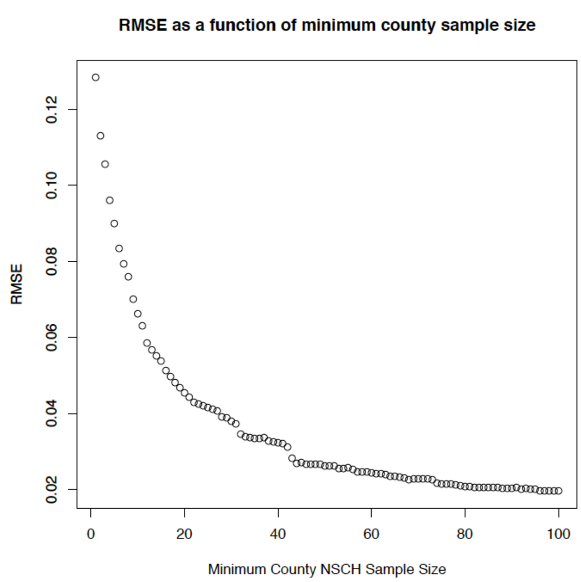


Figure A5. Concordance correlation coefficient as a function of minimum county sample size of *overweight alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data. (Data source: 2003 and 2007 NSCH)

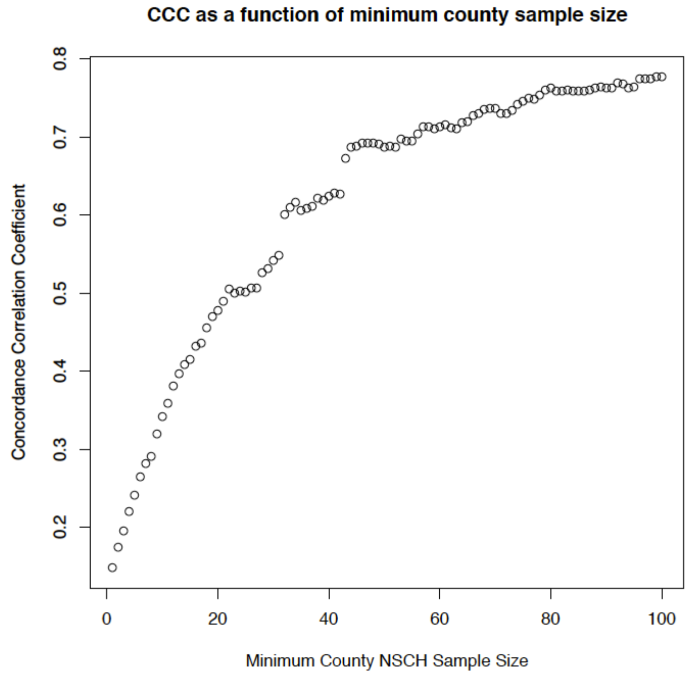


Figure A6. Model-based predicted estimates of *overweight alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data [Census division model]

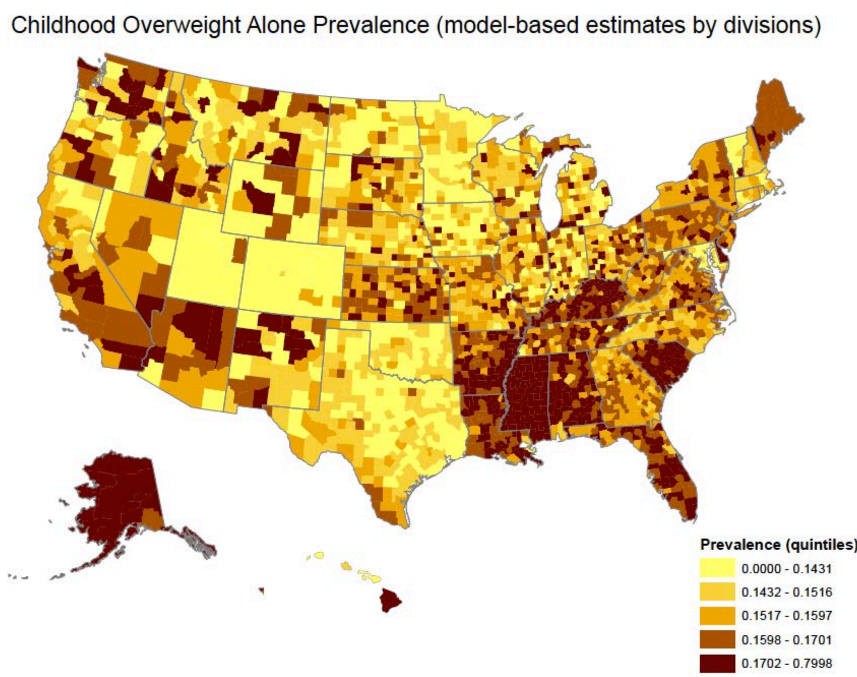


Figure A7. Root-mean-square-error as a function of minimum county sample size of *obesity alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data. (Data source: 2003 and 2007 NSCH)

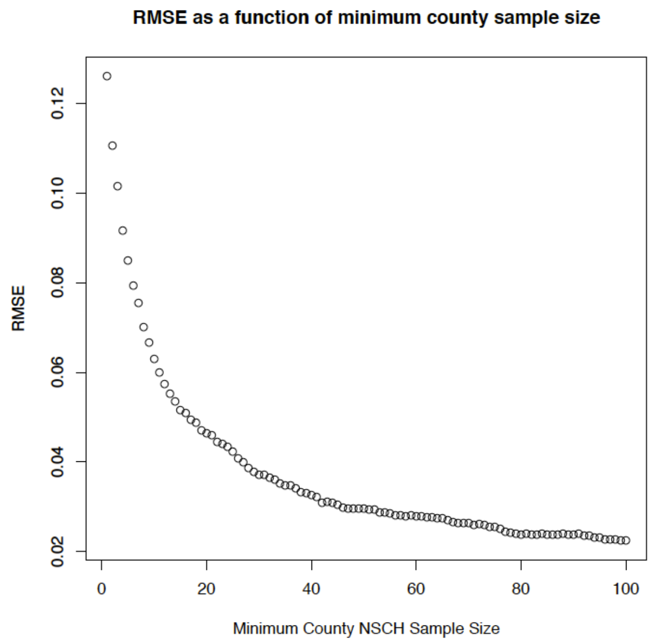


Figure A8. Concordance correlation coefficient as a function of minimum county sample size of *obesity alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data. (Data source: 2003 and 2007 NSCH)

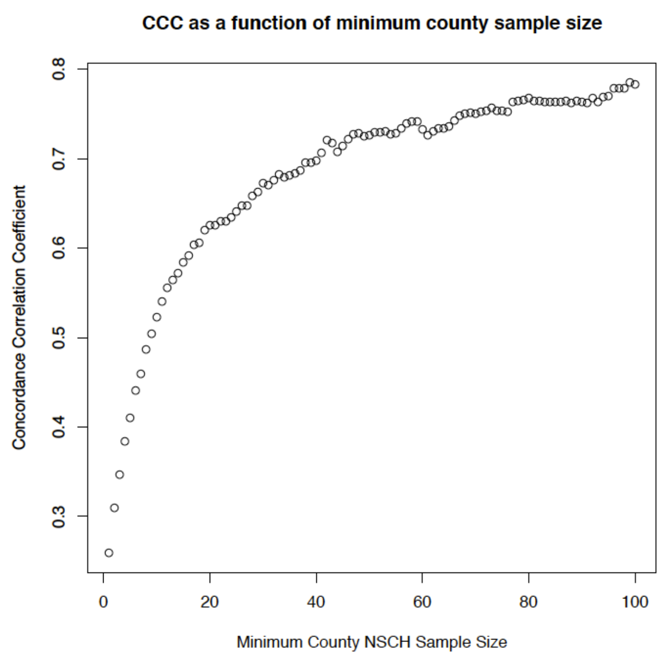


Figure A9. Model-based predicted estimates of *obesity alone* prevalence among US children (10-17 years) for US counties, using 2003 and 2007 NSCH data [Census division model]

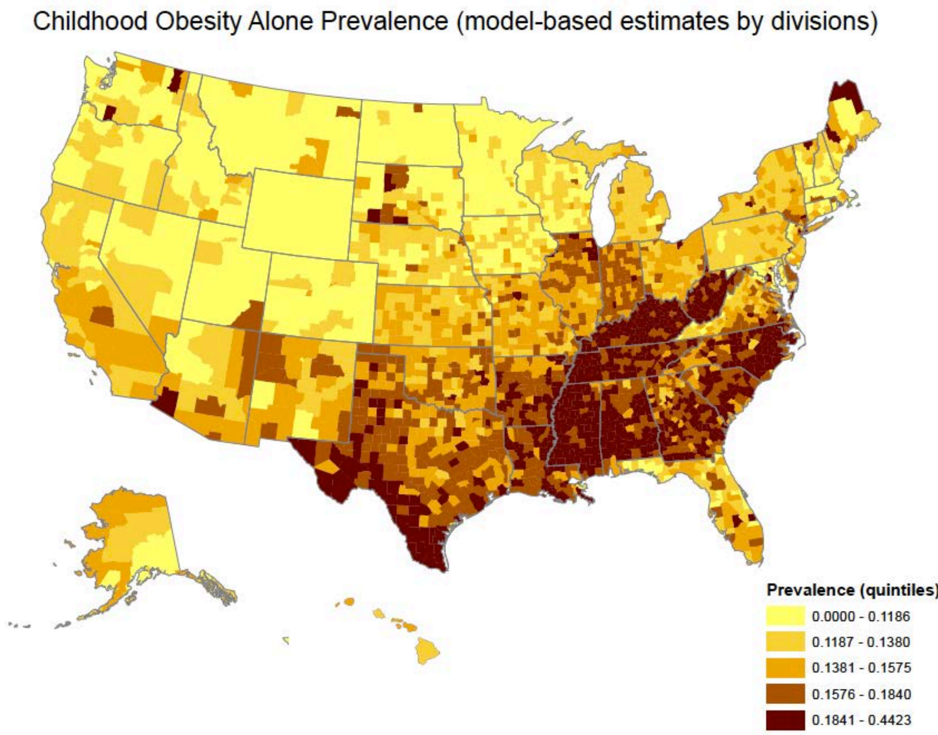


Figure A10. Emory University Institutional Review Board (IRB) Exemption of Human Subjects Research letter

EMORY UNIVERSITY | Institutional Review Board

October 24, 2011

Jessica Cook
Principal Investigator
Epidemiology

RE: **Exemption of Human Subjects Research**
IRB00051902
Bayesian small area estimates of overweight and obesity prevalence by county among U.S. children from 2003 to 2007

Dear Principal Investigator:

Thank you for submitting an application to the Emory IRB for the above-referenced project. Based on the information you have provided, we have determined on **10/24/2011** that although it is human subjects research, it is exempt from further IRB review and approval.

This determination is good indefinitely unless substantive revisions to the study design (e.g., population or type of data to be obtained) occur which alter our analysis. Please consult the Emory IRB for clarification in case of such a change. Exempt projects do not require continuing renewal applications.

This project meets the criteria for exemption under 45 CFR 46.101(b)(4). Specifically, you will collect aggregate data on childhood obesity from a private data set. Analysis of this data set includes access to county-level identifiers.

- Protocol document, version date 7/25/2011, approved

Please note that the Belmont Report principles apply to this research: respect for persons, beneficence, and justice. You should use the informed consent materials reviewed by the IRB unless a waiver of consent was granted. Similarly, if HIPAA applies to this project, you should use the HIPAA patient authorization and revocation materials reviewed by the IRB unless a waiver was granted. CITI certification is required of all personnel conducting this research.

Unanticipated problems involving risk to subjects or others or violations of the HIPAA Privacy Rule must be reported promptly to the Emory IRB and the sponsoring agency (if any).

In future correspondence about this matter, please refer to the study ID shown above.
Thank you.
Sincerely,

Sam Roberts, CIP
Research Protocol Analyst

This letter has been digitally signed

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