PREDICTORS OF DIFFERENCES IN ADOLESCENT ADIPOSITY TRENDS AND WEIGHT-RELATED BEHAVIORS AMONG STATES IN THE UNITED STATES

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ABSTRACT

Predictors of differences in adolescent adiposity trends and weight-related behaviors among states in the United States

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Background: Many states took legislative action to reduce youth obesity in recent years. A "plateau" in youth obesity from 1999 to 2006 was found in a nationally representative sample, leading to speculation that policies have been effective, but the impact of state policies has not been extensively studied. Legislative activity and youth obesity vary by state, suggesting that the national plateau in youth obesity may not be particularized to all states. **Objectives:** To estimate between-state variation in time trends of adolescent adiposity and weight-related behaviors, and the association between state policy changes and adolescent soda consumption and adiposity. **Methods:** Mixed models estimated between-state variation in time trends of body mass index (BMI) percentile and several diet and physical activity behaviors, using cross-sectional data from 272,044 students in 29 states in the 2001, 2003, 2005, and 2007 Youth Risk Behavior Survey. A state-level case-control analysis compared states with disparate trends with respect to behavioral, demographic, and contextual changes. Using data from the 2000 and 2006 School Health Policies and Programs Study, mixed models estimated the association between state policy changes targeting junk food in schools and 2007 soda consumption and BMI percentile, and tested for racial/ethnic differences in the association. **Results:** State BMI percentile trends were similar despite differences in state behavioral trends. Boys experienced a modest linear increase in BMI percentile (ß = 0.18, 95% confidence interval (CI): 0.07, 0.30) and girls experienced a non-linear increase that suggested a decelerating trend ($ß_{linear} = 1.10$, $ß_{quad} = -0.08$). TV viewing was the only behavior associated with BMI percentile among students and BMI percentile time trends across states. Policy changes were associated with lower soda consumption among non-Hispanic Blacks (≤1.33 fewer servings/week), but not with BMI percentile among any racial/ethnic group. **Conclusion:** State policy changes may have affected student behaviors, but not sufficiently to affect adiposity. Adolescent adiposity increased across states in 2001-2007, particularly among girls. Students may compensate for isolated policy changes through behaviors outside of school and environmental factors beyond a school's jurisdiction (e.g., TV marketing). Future research should explore the effect of comprehensive policy change across sectors.

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LIST OF ABBREVIATIONS

BMI	Body mass index
BRFSS	Behavioral Risk Factor Surveillance System
CDC	Centers for Disease Control and Prevention
DAG	Directed acyclic graph
GEE	Generalized estimating equations
ICC	Intraclass correlation coefficient
MTF	Monitoring The Future
NHANES	National Health and Nutrition Examination Survey
NSCH	National Survey of Children’s Health
PE	Physical education
SES	Socioeconomic status
SHPPS	School Health Policies and Programs Study
TV	Television
YES	Youth, Education, and Society
YRBS	Youth Risk Behavior Survey
YRBSS	Youth Risk Behavior Surveillance System

INTRODUCTION

Obesity among youth tripled in the United States from 1980 to 2000 [1] despite numerous public health interventions designed to educate youth about the benefits of a healthy diet and physical activity.[2-4] The failure of this individual-oriented approach led many obesity researchers and policymakers to promote policy as an intervention tool after witnessing the success of full adoption of public policies targeting other public health issues (e.g. tobacco, seat belts).[5-8] State bills and resolutions targeting youth obesity increased substantially in the past decade,[9] targeting school-based resources such as recess, physical education requirements, and vending machines. Little research on state-level policies has been conducted, however, so it is unknown whether such policies have had any effect on diet, physical activity, or adiposity among youth.

Although youth obesity prevalence increased from 1980 to 2000, a recent study reported that there was no significant national increase between 1999 and 2006.[10] This absence of change led the authors to speculate that policies implemented in the past decade could be having a positive effect. Legislative activity varied substantially across states, however,[9] and this raises the question of whether the reported national plateau is obscuring between-state differences in youth BMI trends. As Alvardo et al. discussed in their analysis of *Healthy People 2010* goals,[11] one must consider how achieving goals for the population overall will affect health disparities. If policies have the intended effect, then the legislative disparities could lead to different trends across states, help explain the lack of increase in the country overall, and exacerbate geographic disparities in youth obesity at the same time.[12]

Policies may also worsen racial/ethnic disparities in obesity even if they are effective in the overall population. Compared to non-Hispanic Whites, racial/ethnic minorities have more access to fast-food restaurants and other establishments that provide high-caloric-density, low-nutrient-density foods and beverages.[13-15] This access may allow minorities to compensate for policy changes by obtaining different foods and beverages from different sources. Students' ability to compensate has led some researchers to question the effectiveness of policy interventions.[13, 15] If policies were less effective among minorities, it would worsen the racial/ethnic disparities in youth obesity that already exist.[16] This is only speculation, however, because the little policy research that has been conducted has primarily focused on racial/ethnic majority populations.[17]

The overarching goal of this work was to determine if policy changes passed by states in recent years have had a positive impact on adolescent dietary intake and adiposity. The effect of policies was studied from a socioecological framework in which several determinants of adiposity, at the individual and state levels, were considered. A secondary objective was to determine if any positive impacts of state policy have had unintended consequences on either geographic or racial/ethnic disparities in adolescent diet and adiposity. In short, the purpose was to determine if legislative action by states has brought the United States closer to achieving one of the goals of *Healthy People 2010* (reducing obesity overall) at the expense of another (reducing health disparities).[18]

REVIEW OF LITERAUTRE

Obesity among youth

Consequences

Obesity has severe physical, psychosocial, and economic consequences during childhood and across the lifespan. Effects at an early age include type 2 diabetes, hypertension, dyslipidemia, sleep apnea, negative body image, low self-esteem, and depressive symptoms.[19] Obesity during childhood also tends to track into adulthood,[19] during which it is associated with cardiovascular disease, diabetes, several types of cancer, sleep disorders, and all-cause mortality.[20] The long-term consequences of youth obesity were observed in a cohort study of 5,063,622 person-years of follow-up, in which higher BMI during childhood was associated with an increased risk of coronary heart disease during adulthood.[21] The number of deaths in the U.S. attributable to obesity exceeds that of any other risk factor except tobacco, due to the effects of obesity combined with the high prevalence.[22]

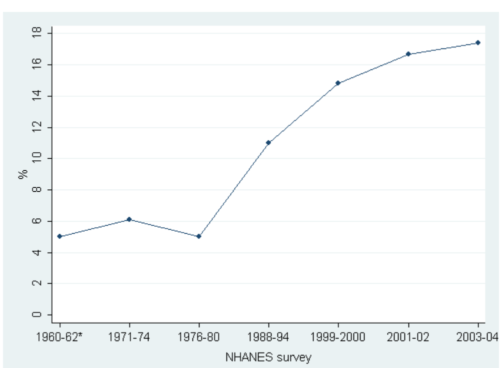
As the U.S. population ages, the long-term effects of youth obesity are likely to become an even greater public health burden. Bibbins-Domingo et al. projected that the prevalence of coronary heart disease in the U.S. will increase 5-16% by 2035 as a result of obesity among today's adolescents, resulting in an increase of 100,000 prevalent cases.[23] Olshansky et al. projected that life expectancy in the U.S. may cease to increase or even decline in the first half of the 21st century as a result of obesity.[24] Obesity is already responsible for $92.6 billion (in 2002 dollars) in medical spending[25] and $64 billion (in

2003 dollars) in indirect costs[26] in the U.S., and the economic toll is likely to increase along with the age of the U.S. population.

Trends over time

Despite widespread knowledge of these consequences, the prevalence of obesity steadily increased from 1980 to 2000. "Obesity" here is defined as equal to or above the age- and sex-specific 95th percentile.[27] Data from the National Health and Nutrition Examination Surveys (NHANES) show that the prevalence of obesity among adolescents, 12-19 years old, was relatively low and stable at 5% in the U.S. throughout the 1960s and 1970s, but increased to 11% between NHANES II (1976-80) and NHANES III (1988-94).[28] More recently, the prevalence increased from 15% in 1999-2000 to 17% in 2003-04, though a recent study by Ogden et al. reported no significant change between 2003-04 and 2005-06 and no overall change from 1999-2006.[10] Even in the absence of recent change, the national prevalence of adolescent obesity is more than three times as high as the *Healthy People 2010* goal (5%).[18] The steady, but slowing increase in youth obesity over time is exhibited by the curvilinear graph in Figure 1.

Figure 1. Obesity prevalence among adolescents, age 12-19*, in United States, 1960-2004



* 1960-62 data are from National Health Examination Survey and include ages 12-17

No population group has been immune from the increase. Wang and Zhang examined four waves of NHANES data by age, gender, race, and socioeconomic status (SES), and found that youth obesity increased in every stratum from 1971 to 2002.[29] There have been consistent disparities across race/gender groups, however, with Hispanic males and non-Hispanic Black females having a higher prevalence of adolescent obesity.[16] In 2003-06, the prevalence of adolescent obesity ranged from 9% in non-Hispanic White females to 16% in Hispanic males and 20% in non-Hispanic Black females.[10]

Causes of increase in obesity prevalence

Obesity in any individual results from an imbalance between energy intake and energy expenditure. The human body regulates the imbalance, or ‘energy gap’, by storing the majority of excess energy as fat.[30] During the same period in which obesity prevalence increased, several behaviors that affect intake or expenditure exhibited temporal trends that suggest a growing energy gap in the youth population in the U.S. There have been increases among youth in the number of snacks per day,[31] consumption of sweetened beverages,[32] and the percentage of meals eaten at restaurants or fast food businesses,[33] and decreases in the percentage of trips to school that are done by walking and the percentage of high school students who report taking physical education (PE) class at least once per day.[34] A national panel of obesity experts reported that many of these variables have been associated with youth obesity in observational and experimental studies.[34]

Soft drinks, in particular, became a greater source or energy intake among adolescents during the same period in which obesity prevalence escalated.[35-37] The proportion of energy intake from soft drinks increased among 2-18 year-olds from 3.0% in 1977-78 to 5.5% in

1994-96.[36] More recently, sugar-sweetened beverage consumption continued to increase primarily among racial/ethnic minorities. Per capita intake of sugar-sweetened beverages among 12-19 year-olds changed little among Whites between 1988-94 and 1999-2004, but increased from 268 to 297 kilocalories (kcal)/day among Blacks and from 248 to 305 kcal/day among Mexican-Americans.[37] Approximately 67% of sugar-sweetened beverage intake among adolescents in this time period came from soda.[37] Two systematic reviews reported that soft drinks have been associated with energy intake and weight gain in several cross-sectional and prospective cohort studies,[38, 39] although other reviews were reluctant to conclude that there is a causal effect due to the lack of evidence from interventions.[40, 41]

It is widely believed among obesity experts that these behavioral trends are partially attributable to the increasingly "obesogenic" environment in the U.S. Many environmental trends that appear to promote energy intake or discourage energy expenditure have been observed during the time period in which obesity prevalence increased:

- In 2000, 43% of elementary schools, 74% of middle schools, and 98% of high schools had vending machines, school snack bars, or other food sources outside of the school meal program.[42]
- In 1967-97, the number of locations where ready-to-eat foods can be purchased (e.g., restaurants, snack bars) more than doubled while the number of food stores declined by ~15%.[43]
- In 1972-92, the output of processed food in the U.S. food system grew by 41% (in 1987 dollars).[44]
- The proportion of homes with more than one television increased from 35% in 1970 to 75% in 2000.[45]

- The portion sizes of most food manufacturers' products have increased over the past 3 decades.[46]
- As urban sprawl has increased in many metropolitan areas,[47] individuals have become more reliant on automobiles for transportation and less on walking, biking, or public transportation.[48]

Though the causal mechanisms between these environmental factors and youth obesity have not been established, some recent studies have suggested that racial/ethnic disparities in built environment resources may account for the racial/ethnic differences in youth obesity.[14, 15, 49] "Built environment" is defined as "aspects of a person's surroundings which are human-made or modified."[50] Delva et al. found that Hispanic students were more likely to have access to brand-name fast foods and ice cream through vending machines at school compared to white students (though they were also more likely to have access to fruits and vegetables), while African-American students were less likely to have access to low-fat salty snacks, fruits, and vegetables compared to white students.[49] Sturm reported that Hispanic youth were more likely to attend schools surrounded by convenience stores, snack stores, restaurants, or off-licenses.[15] Recently, a systematic review concluded that Blacks, Hispanics, and low-SES groups were at a disadvantage with respect to food stores and fast-food outlets.[14]

The rapid increase in obesity during a period of behavioral and environmental changes suggests that obesity is driven by factors outside of human biology. Nonetheless, twin, adoption, and family studies have established that obesity has a large genetic component. Heritability estimates have ranged from 6% to 85% across different populations, and as of January 2007, 127 candidate genes had been associated with obesity-related phenotypes.[51] This does not dispute the role of environmental factors. Migration studies have illustrated the interplay between genes and environment by comparing obesity prevalence in populations of similar genetic background who reside in different environments. Multiple studies found that Japanese adults living in Japan had significantly lower average BMI than Japanese adults living in Hawaii or California.[52, 53] A study of Pima Indians found that the prevalence of obesity among Pima males and females living in Mexico was 7% and 20%, respectively, while the prevalence among Pima males and females living in the U.S. was 64% and 75%, respectively.[54] In comparison, the prevalence among the U.S. adult population prior to this study (1988-94) was 21% and 26%, respectively.[55] These data illustrate that obesity prevalence can differ between genetically similar populations in different environments or between genetically distinct populations in a common environment. This complex interplay between genes and environment must be considered while examining changes in obesity over time within a geographic region. As populations migrate and react differently to a dynamic environment, temporal changes in obesity prevalence can result from any combination of demographic, behavioral, and environmental changes within a region.

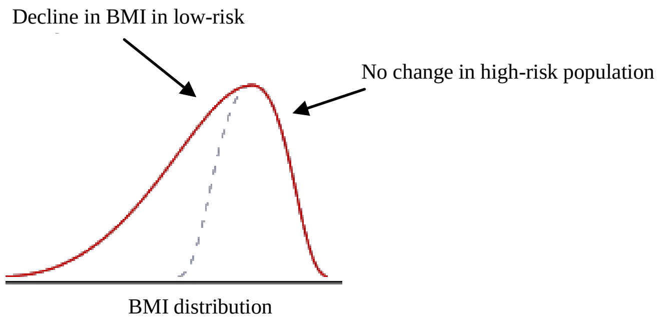
Interventions to reduce youth obesity

Addressing the complex causal web of behavioral, environmental, and biological determinants of obesity has been an ongoing challenge for the past three decades. Researchers have designed and implemented dozens of behavioral interventions to reduce obesity, but results have been disappointingly modest.[2-4] Thomas reported that among fifty-seven randomized trials that were designed to reduce youth obesity and published in 1985-2003, only four found a statistically and clinically significant difference between the intervention and control groups.[4] Flynn et al. reviewed 147 youth obesity interventions published in 1982-2003, and reported that most interventions were able to achieve at least one positive short-term outcome, but 'no one programme emerged as a model of best practice.'[2] Summerbell et al. published an updated review of interventions that were published in 2000-04 and reported that few were able to impact child weight status to a significant degree.[3]

Most obesity interventions to date have been designed to educate youth to reduce their caloric intake or be more physically active. The review by Flynn et al. reported that the most common intervention strategy was diet/activity education, employed by 69% of the 147 interventions they reviewed.[2] Many experts have argued that focusing on educating individuals, while important, ignores the broader social, cultural, and environmental factors that influence population health.[56-59] In an obesogenic environment, individual education cannot be expected to have an effect without changing the culture and environment to which individuals are continuously exposed.

Another flaw of individual-based obesity interventions is that many have not targeted high-risk populations. The review by Summerbell et al. noted that several recent obesity interventions appeared to seek well-educated samples.[3] Interventions that focus on diet and activity education often rely on recruiting individuals who are motivated to join and participate, who have the socioeconomic resources to follow intervention prescriptions, and to whom the intervention strategies are tailored and culturally appropriate. This can translate into helping populations who are already at a low risk, and the danger of this approach is illustrated in Figure 2.[60]

Figure 2. Illustration of a potential increase in BMI disparity following an obesity intervention*



* Adapted from Frohlich et al.

The figure represents the hypothetical BMI distribution of a sample before and after an intervention that was designed to reduce obesity. Pre- and post-intervention distributions are represented by dashed and solid lines, respectively. In the Figure 2 scenario, individuals with low BMI lost weight while those with high BMI did not, causing the overall distribution to be "stretched" rather than "shifted." This could occur if, for example, the intervention is successful only among non-Hispanic White females of high SES who are already at a relatively low risk for obesity[16, 61] and have the resources to follow the intervention. The end result can be a significant intervention effect overall if the decline in low-risk groups is large enough to reduce the mean BMI in the total sample. This heterogeneous effect would only exacerbate BMI disparities. Even "successful" interventions can thereby have a negative public health impact if they are not implemented on a broader level to reach high-risk populations.

Policy as an intervention tool

As part of the movement to make interventions more population-based, policy has been widely promoted as an intervention tool.[5-8, 62] "Policy" has been defined as "a legislative action, organized guidance or rule that may affect the environment or behavior of people or institutions."[63] Policies have several advantages over conventional individual-based interventions. They are often implemented on a broader population level (e.g., county, state, or country) and do not depend on recruiting and retaining individuals. They often involve changing the environment by creating health-promoting resources (e.g., water fluoridation) or eliminating unhealthy resources (e.g., tobacco advertising to youth), rather than assuming that individuals live and work in an environment where they have access to resources. Finally, a well-implemented policy can reach all individuals within its jurisdiction, usually making it less expensive per person compared to individual-based interventions that target a relatively small number of people.

Public policies have already had a profound effect on other health issues in the United States. In a review of the 10 great public health achievements of the 20th century[64], each of the achievements was influenced by policy change such as seat belt laws or regulations governing permissible workplace exposures. A review of bicycle helmet legislation found that the change in the proportion of helmet use in cyclists after the introduction of laws ranged from +5% to +54%; odds ratios measuring the effect of legislation ranged from 1.24 to 22.25, though the authors acknowledged that this may suggest publication bias.[65] A review of seat belt laws reported that the median percentage change in seat belt use following enactment of laws was 21%.[66] Youth obesity experts often cite tobacco control policies as a model intervention because these policies have been effective in school settings. Though not universally successful,[67-69] school-based smoking policies have been associated with lower rates of daily and non-daily smoking among youth in several independent studies.[70-74]

Certain policies have been particularly successful among racial/ethnic minorities and populations of low SES. The review of bicycle helmet laws found that the magnitude of effect was greater in low-SES neighborhoods.[65] A review of tobacco policies and racial disparities suggested that Black and Hispanic adolescents may be more responsive to changes in cigarette prices than White adolescents.[75] These results suggest that policies, if appropriately chosen to target racial/ethnic or socioeconomic groups in which they are effective, have the potential to reduce racial and socioeconomic health disparities. One can only speculate about this benefit, however, because nutrition and physical activity policy interventions have primarily focused on racial/ethnic majority populations to this point.[17]

Growth of state obesity policies

The success of policies designed to target other health issues led both researchers[5, 7, 62] and U.S. congressmen[6, 8] to argue that states should implement policies to reduce youth obesity. In 2003-05, states proposed 717 bills and 134 resolutions related to youth obesity, and adopted 17% and 53% of them, respectively.[9] Within this time period, the number of bills and resolutions per year increased from 239 in 2003 to 394 in 2005. Legislative activity varied substantially across states, as the total number of bills and resolutions ranged from 0 (Wyoming) to 63 (Illinois). The proportion of legislation that was adopted also varied from 0% (several states) to 80% (Nevada).

Recent studies examined determinants of state legislative activity and found that certain state-level characteristics are associated with proposal or enactment of legislation.

Cawley et al. reported that in 2003-06, the introduction of anti-obesity bills was positively associated with state-level per capita income, percentage of college-educated adults, percentage of population in poverty, and mean percent difference between actual and desired weight among adults, and negatively associated with percent of the workforce in agriculture.[76] They also found that the enactment of state laws was positively associated with having a Democratic governor, percentage of the population that was Black, and mean percent difference between actual and desired weight among adults.[76] Boehmer et al. reported that the enactment of childhood obesity-related bills in 2003-05 was associated with having a 2-year legislative session, Democratic control of both chambers, and the percentage of adults who did not complete high school.[77] In a separate study, Boehmer reported no association between adult obesity prevalence and the introduction of state legislation,[9] but Cawley et al. reported a negative association between adult obesity prevalence and the enactment of laws.[76] Nanney et al. reported that youth obesity prevalence was positively associated with policies related to food services and nutrition.[78]

School-based obesity policies

Several national health organizations have asked schools to take a lead role in promoting physical activity and nutrition among youth.[79-81] Schools provide organization, support, and structure to facilitate a variety of different activity- and nutrition-related programs, and many of these programs have been promoted by state policies. The majority of the 851 bills and resolutions that were proposed in 2003-05 were school-based,[9] targeting areas such as:

- Nutrition standards and vending machines (e.g., restrict access to vending machines and competitive foods, regulate marketing of foods and beverages with little nutritional value, n=238)
- Physical education and physical activity (e.g., require time and frequency of PE classes, limit substitutions and waivers for PE, n=191)
- Safe routes to school (e.g., provide bicycle facilities, crossing guards, and traffic-calming measures to promote walking/biking to schools, n=47)
- Body mass index reporting (e.g., require or allow schools to measure and report students' BMI to parents, n=39)
- Model school policies (e.g., require state agencies or education officials to develop model school policies, n=15)

Among these areas, the proportion of bills that were adopted ranged from 13% (nutrition standards and vending machines) to 29% (model school policies).[9]

Policy research

Despite the growing movement to use school-based policies as an intervention to reduce obesity, the paradigm shift away from individual education has been slow. Flynn et al. evaluated interventions' level of upstream investment – defined by the authors as the 'extent to which strategies are focused on broader groups and areas of action such as society as a whole and policy change as opposed to treatment of individuals' – and ranked 67% of interventions as having 'low' investment.[2]

The increase in state legislation has also not been accompanied by studies to evaluate the effect of state policy changes. Obesity policy research has generally been limited to surveillance, cross-sectional analyses, and quasi-experimental studies that evaluated the effects of policy interventions in individual states or districts. Studies have generally focused on policies set by the school district, with less emphasis on policies set by the state.

Surveillance

The Centers for Disease Control and Prevention (CDC) has been collecting school-based policy data since 1994 through the School Health Policies and Programs Study (SHPPS). SHPPS collects data on policies at the state, district, school, and classroom level, from nationally representative samples every six years (1994, 2000, and 2006). Details on SHPPS are provided in the Methods.

Data from the 2000 SHPPS pointed out several areas where policies could potentially target youth obesity:

- Four percent of states required that elementary schools provide regularly scheduled recess.[82]
- Eight percent of elementary schools, 6% of middle/junior high schools, and 5% of senior high schools required daily PE. The percentage of schools that required *any* PE declined across grades from 51% in 1st grade to 5% in 12th grade.[82]
- Thirty-five percent of schools provided access to physical activity facilities and spaces outside of normal school hours.[82]

- Zero states required schools to offer fruits and vegetables during breakfast/lunch or in vending machines, and only 8% required that schools prohibit junk food in vending machines.[42]
- Sixteen percent of states offered certification for school food service managers, and 10% of states required it.[42]
- Twenty-six percent of elementary schools, 62% of middle/junior high schools, and 95% of senior high schools offered food in vending machines. The three most common types of foods and beverages in vending machines and school stores, canteens, and snack bars were soft drinks, sports drinks, or fruit drinks that are not 100% fruit juice; salty snacks that are not low in fat; and cookies and other baked goods that are not low in fat.[42]

Echoing the state policy changes that were described, many changes to improve school food environments or increase physical activity were observed when comparing SHPPS data in 2000 and 2006. Table 1 gives examples of state policies that increased between these years.

Table 1. Percentage of states with policies targeting obesity, SHPPS 2000 and 2006

State-level policy	2000 (%)	2006 (%)
Require schools to prohibit junk foods in vending machines[83]	8.0	32.0
Require elementary schools to provide students with regularly scheduled recess[84]	4.1	11.8
Require schools or districts to follow *National Standards for Physical Education*[84]	59.2	76.0
Require newly hired staff who teach PE at the elementary school level to have undergraduate or graduate training in PE[84]	51.1	64.7

Youth, Education, and Society (YES) is a separate study funded by the Robert Wood Johnson Foundation that began annually collecting data on school policies related to nutrition and physical activity in 2003.[85] The policy data collection takes place in conjunction with Monitoring the Future (MTF), a study of nationally-representative samples of 8th-, 10th-, and 12th-grade students. Data from YES and MTF indicated that there was a decrease in availability of regular-sugar/fat food items in middle schools and high schools from 2004 to 2007, and an increase in availability of some reduced-fat items in school lunch or à la carte.[86] Analyses of YES and MTF data also revealed socio-demographic disparities in school policies regarding PE requirements and fitness tests.[87] Similar to the racial/ethnic and socioeconomic disparities in environmental resources that were noted earlier, these disparities generally favored high-SES and non-Hispanic White students.

Observational studies of school policies

Two reviews of policy interventions, published in 2006 and 2009, suggested that certain types of school policies can have a positive impact of student diet and physical activity.[17, 88] Studies have generally focused on behavioral outcomes, however, leaving the question of whether policies can reduce youth adiposity.

The authors of the 2006 review reported that most interventions that focused on diet were designed to promote the availability of healthy foods.[17] As the authors pointed out, an *Institute of Medicine* report concluded that this approach is not sufficient to reduce obesity because of the availability of high-fat, high-sugar foods in schools and the community.[89] Some researchers have speculated that policies will not affect adiposity even if they affect individual behaviors because students can compensate through alternative foods and providers.[13, 15] In 2002, for example, a school district in Harris County, TX, removed snack foods and sweetened beverages from middle school snack bars, but did not exert any control over school vending machines. The researchers who evaluated the policy change found that it led to a decrease in consumption of foods sold at snack bars, but an increase in vending machines and consumption of snack foods from vending machines as students compensated for the snack bar changes.[90]

The 2006 review did not go into detail about different types of school-based food policy interventions, but the 2009 review reported that interventions that focused on promoting nutrition guidelines were more effective than those focused on regulating food and beverage availability.[88] The authors noted the Harris County study as they questioned if students' ability to compensate will limit the effectiveness of policies that restrict individual foods or sources. They reported that only one of the 18 studies in the review examined BMI as an outcome (Sahota et al. tested the effect of a comprehensive policy intervention on BMI, but detected no difference at 1-year follow-up.)[91, 92]

Recently, two school- and community-based interventions reported positive effects on youth adiposity when policies were utilized as a tool within a comprehensive intervention. Foster et al. found that a multicomponent school-based intervention that included changes in food availability in cafeterias was able to prevent the development of overweight among students in grades 4-6.[93] Economos et al. implemented a community-based intervention with similar school cafeteria changes and found that BMI z-scores among children in grades 1-3 decreased significantly more in the intervention community compared to two control communities.[94]

State policy studies

Studies in Arkansas and Texas evaluated the effect of state legislation targeting obesity by comparing measures of diet and adiposity pre- and post-legislative change. In 2003, Arkansas passed legislation that included banning vending machines in elementary schools and requiring that each student's BMI be reported to their parents. The prevalence of overweight among children in the state did not increase between Year 1 and Year 3 of implementation of the legislation.[95] In 2004, Texas implemented a statewide policy restricting portion sizes, availability, and frequency of servings of high-fat foods and sweetened beverages in all school food sources. Compared to the years prior to policy implementation, students reported more consumption of several nutrients and less consumption of snack chips and sweetened beverages at lunch.[96] Texas also passed legislation which required public middle school students to engage in 30 minutes of physical activity per day. In a sample of schools on Texas-Mexico border, there was a significant increase in self-reported days of PE per week among students.[97]

To date, only one study has examined the effect of a state-level school-based policy on youth diet, activity, or obesity in a national sample. In a cross-sectional analysis of high school students, Cawley et al. tested the association between state PE policies and PE participation, and subsequently tested the associations between PE participation and days of activity, BMI, and obesity.[98] They found that PE requirement policies were positively associated with minutes of PE per week in both boys and girls, and that minutes of PE were associated with days in which girls participated in 20 or more minutes of vigorous activity. They found no association, however, between minutes of PE and days of vigorous activity in boys, or between minutes of PE and obesity in boys or girls.

Research needs

As noted earlier, Ogden et al. reported that youth obesity in the U.S. did not significantly change between 1999 and 2006[10] after consistently increasing from 1980 to 2000. This "plateau" happened during a period of aggressive state policy change to target youth obesity, but one can only speculate about the effects of these policies due to the paucity of research. The absence of recent change in youth obesity underscores the need to understand what caused the change in trend. As the Institute of Medicine stated in its 2006 report, an essential priority in addressing the obesity epidemic is 'learning what works and what does not work.'[99] There have been encouraging results from cross-sectional studies of state and school obesity policies, as well as single-state longitudinal studies, but in order to attribute the plateau to policy change, there is a need for rigorous research designed to estimate the effect of policy changes on weight-related behaviors and adiposity in a national sample.

One must also consider the negative consequences that policies could have on obesity disparities even if they are effective. Specifically, there is reason to believe that racial/ethnic or geographic disparities in obesity could be exacerbated even if policies have a positive effect in the country as a whole.

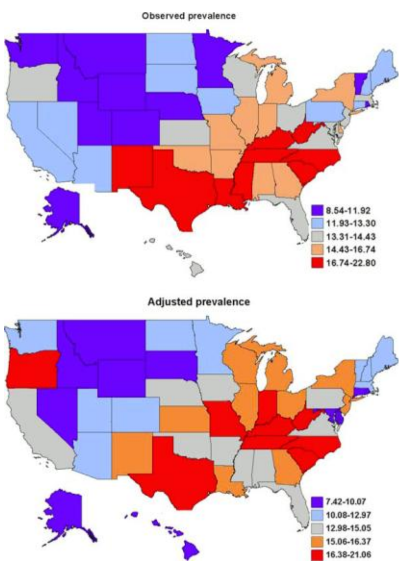
Racial/ethnic differences in the effect of state policies

As noted earlier, some researchers have questioned policy interventions on the rationale that students can easily compensate for policy changes.[13, 15] If vending machines are banned from school, for example, students can simply bring junk food or soda from home instead. Racial/ethnic minorities may be able to compensate more easily than non-Hispanic Whites due to the disadvantages they face in the built environment in school and the community.[14, 15] In his study of food establishments surrounding schools, Sturm speculated that Hispanics could easily negate school policies because of their access to food establishments surrounding school.[15] In addition to testing the effect of policy changes in the population overall, it is critical to compare the effect across racial/ethnic groups to determine if policies can overcome environmental disparities that racial/ethnic minorities face.

Geographic disparities

In addition to the state disparities in legislative activity that were noted earlier,[9] youth obesity prevalence is known to vary by state. Figure 3 displays the state disparities in youth obesity in the U.S. that were reported by Singh et al. using 2003-04 data from the National Survey of Children's Health (NSCH).[12] The prevalence of obesity among youth age 10-17 in NSCH ranged from 9% (Utah) to 23% (Washington D.C.) Using Utah as the referent state, the odds of being obese were significantly elevated in most states after accounting for age and gender. Further adjustment for racial and socioeconomic differences reduced the relative odds in most states, particularly in the South, but twenty-five states still had significantly elevated odds. Geographic clustering of obesity by state, province, or other region is a common finding worldwide. Studies in Canada,[100] Austria,[101] and Australia[102] found geographic disparities in youth adiposity, while studies in England,[103] Scotland,[104] India,[105] and France[106] found the same to be true of adult obesity.

Figure 3. Observed and adjusted* prevalence of adolescent obesity, 2003-04, National Survey of Children's Health



* Adjusted for age, gender, race, household composition, place of residence, language use, household poverty status, neigborhood safety, social capital, television viewing, recreational computer use, physical activity, and sports participation

When cross-sectional state disparities in obesity and legislative activity are considered in conjunction, it raises an important question: Do Ogden et al.'s findings represent a national trend or a heterogeneous collection of state trends in which youth obesity is increasing in some states while decreasing in others? Ogden et al.'s results cannot be particularized to all states because they were based on a nationally representative sample. State variation in time trends could result in both state disparities, such as those reported by Singh et al.,[12] and an absence of change in the country overall. Moreover, between-state differences in youth obesity time trends could cause obesity disparities to either improve or worsen over time.

State disparities in legislation are only one causal mechanism by which adiposity trends could differ by state. As with cross-sectional geographic disparities, between-state variation in time trends of youth adiposity could result from a complex interplay of demographic, behavioral, and environmental differences between states. If trends in specific behaviors differ between states in which adiposity reached a plateau and those where it did not, it would suggest areas where state legislation may have had an impact and identify areas for intervention in states with unfavorable trends. One must also consider, however, that population movement alone can cause large changes in obesity prevalence, as demonstrated by migration studies described earlier.[52-54] Du et al. argued that many longitudinal studies ignore population shifts that occur during follow-up, and such demographic changes must be considered particularly when studying larger geographic areas such as states that are more dynamic.[107] Demographic changes may be responsible for obesity change because of either demographic disparities in obesity[16] or state policies that are not suited to changing populations. In the contemporary obesogenic environment in which youth in the U.S. live, care must be taken to identify variables that account for any shifts in adiposity trends before attributing the plateau to policy change.

Public health impact

This research will be of interest to state policy makers because it will determine if youth adiposity has been increasing, decreasing, or stagnant on the state level in recent years, and identify factors, policy-related or otherwise, that distinguish states with disparate trends. It will begin with presenting a macro picture of between-state differences in behavioral and adiposity trends while exploring a wide range of behavioral, demographic, and contextual determinants of such differences, and then focus more narrowly on specific state policies that may explain differences in adiposity. Each step will involve determining if positive trends in the country overall apply equally to populations that have historically been at a greater risk for obesity. Collectively, this will estimate the effect of policy interventions that have already taken place and identify areas for future intervention – to reduce not only adolescent adiposity, but health disparities as well.

SPECIFIC AIMS

National youth obesity did not increase from 1999 to 2006.[10] The "plateau" was based on a nationally representative sample and thus cannot be particularized to each of the 50 states and the District of Columbia. Some states aggressively passed legislation to target youth obesity between 1999 and 2006, while other states did little.[9] This variation suggests that the absence of increase may be due to a combination of disparate trends across states. Variation in time trends could theoretically exacerbate the geographic disparities in youth obesity that exist already, even if youth obesity is not increasing.

In addition to exploring state differences in time trends of adolescent adiposity and weight-related behaviors, the objective of this work was to test whether state policy changes targeting junk food in schools are associated with these outcomes. This involved estimating the overall effect as well as differences in the effect across racial/ethnic groups. This will confront the speculation posed by others that policies can be negated by built environment disadvantages that minorities face outside of school.[15]

Specifically, the aims were as follows:

Aim 1: To estimate between-state variance in time trends of adolescent adiposity and weight-related behaviors from 2001 to 2007, and to determine if state-level adiposity trends are associated with demographic, behavioral, or contextual differences between states.

Aim 2: To determine if changes in state-level policies targeting junk food in schools that took place between 2000 and 2006 are associated with adolescent soda consumption and adiposity in 2007, and to estimate differences in this association by race/ethnicity.

Aim 1 was accomplished using a time series design and linear mixed models to estimate between-state variation in time trends of BMI percentile and several diet and physical activity behaviors from 2001 to 2007. This secondary analysis employed data from 272,044 students in 29 states collected across 4 survey years (2001, 2003, 2005, and 2007) as part of the state Youth Risk Behavior Surveillance System (YRBSS). After estimating between-state variation in time trends, a state-level case-control design was used to identify demographic, behavioral, or contextual variables that distinguished states where adiposity increased during this time period from those where it decreased.

Subsequently, state policy data from 2000 and 2006 were combined with 2007 Youth Risk Behavior Survey (YRBS) data to estimate the association between policy changes targeting junk food in schools and soda consumption and BMI percentile in 2007. Differences in this association across racial/ethnic groups were estimated to determine if policies can reduce racial disparities in soda consumption and adiposity. The hypothesis for Aim 2 was that policy changes would be associated with lower consumption and BMI percentile, and that the effect would be equal or greater in racial/ethnic minorities. This secondary analysis included 90,730 students from 34 states that participated in both the SHPPS in 2000 and 2006 and YRBS in 2007.

METHODS

The analyses utilized data from two surveillance programs administered by the CDC: YRBSS and SHPPS. Both surveys provide data that are representative of individual states and are thus appropriate for studying determinants of state trends.

Youth Risk Behavior Surveillance System

Survey design

YRBSS is a biennial system of national, state, and local school-based surveys of youth health risk behaviors.[108] The surveys have been conducted among students, grades 9-12, in odd-numbered years since 1991. Individual students were not followed over time. The analyses of time trends utilized data from the state YRBS in 2001, 2003, 2005, and 2007. These years were chosen on the basis of the availability of height and weight data, which were first collected in 1999, and to ensure that all student data were collected after the baseline policy data (2000).

States use a two-stage cluster sample design to produce a representative sample of students in their respective jurisdiction.[109] In most states, the first sampling stage involves selecting schools with probability proportional to school enrollment size. In the second stage, classes of a subject or period that all students are required to take are randomly selected, and all students in the selected classes are eligible to participate. Data are weighted in states that have a scientifically selected sample, appropriate documentation, and an overall response rate $\geq$ 60%. A weighting factor is applied to each student to account for student non-response and the grade, sex, and race/ethnicity distribution of students in the state jurisdiction. This ensures that sample data are representative of all 9^{th}-12^{th}-grade students attending public schools within the state.

State, school, and student participation in the surveys were voluntary. The number of years from 2001 to 2007 in which states provided weighted data is displayed in Table 2. Only states that provided data in 3 or 4 years were included in analyses of time trends. Oklahoma and South Dakota were excluded from all analyses because the states judged that their data were not representative of the state racial/ethnic distribution. Nevada was excluded from analyses of time trends because it did not provide students' height and weight data in 2003-2007. These exclusions left 29 states available for the analyses of time trends.

Table 2. Participation in state Youth Risk Behavior Survey in 2001-2007 (four survey years)

# years*	States	n
4	DE, FL, ID, MA, ME, MI, MO, MT, NV, NC, ND, RI, SD, UT, VT, WI, WY	17
3	AL, AZ, AR, DC, GA, IN, KY, MS, NH, NY, OH, OK, TN, TX**, WV	15
2	AK, CT, HI, IA, KS, MD, NE, NJ, NM, SC	10
1	CO, IL	2
0	CA, LA, MN, OR, PA, VA, WA	7

* Number of years that state provided weighted YRBS data
** Texas participated in 4 survey years, but omitted a large metropolitan area in one

The mean, median, and range of the state sample sizes and student, school, and overall response rates for the years of interest are displayed in Table 3.[110-113] Only states that were included in the analyses of time trends are represented in Table 3 (n = 29). The number of states varies across years because states were allowed to miss up to one year and still be included in the analysis. The overall participation rate between 2001 and 2007 ranged from 60% to 90%. State sample sizes ranged from 1,071 (Utah in 2001) to 13,439 (New York in 2007).

Table 3. Sample characteristics across states that were used in analyses of time trends (Aim 1), state Youth Risk Behavior Survey, 2001-2007

	2001	2003	2005	2007
# states that participated	19	26	28	28
Sample size				
Median	2,120	1,781	2,375.5	2,398
Minimum	1,071	1,088	1,140	1,324
Maximum	7,067	9,320	9,708	13,439
Within-state student response rate*				
Mean	81.2	82.2	78.8	78.1
Minimum	69	64	68	69
Maximum	90	94	92	89
Within-state school response rate				
Mean	86.1	86.0	86.6	85.5
Minimum	73	72	72	69
Maximum	97	100	100	100
Within-state overall response rate				
Mean	69.7	67.5	70.7	68.4
Minimum	63	60	60	60
Maximum	77	90	85	82

* Student response rate = (number of useable questionnaires / number of students sampled)

Analyses of policy changes utilized only data from the 2007 YRBS. States were included if they provided weighted data of soda consumption in 2007 and relevant policy data in 2000 and 2006 (n = 34: AR, AZ, DC, DE, FL, GA, HI, ID, IL, IN, IO, KS, KY, ME, MA, MS, MO, MI, NV, NH, NM, NY, NC, ND, OH, RI, SC, TN, TX, UT, VT, WV, WI, WY). Sampling statistics across these states in 2007 are provided in Table 4.

Table 4. Sample characteristics across states that were used in analyses of policy change (Aim 2), state Youth Risk Behavior Survey, 2007

		2007
# states used in analysis		33
Sample size		
	Median	2,083
	Minimum	1,191
	Maximum	13,439
Within-state student response rate*		
	Mean	79.4
	Minimum	62
	Maximum	92
Within-state school response rate		
	Mean	85.3
	Minimum	69
	Maximum	100
Within-state overall response rate		
	Mean	67.3
	Minimum	60
	Maximum	82

* Student response rate = (number of useable questionnaires / number of students sampled)

Variables

YRBS data were collected using a written questionnaire administered in class. Students were asked to report their age, sex, race (White, Black/African-American, Asian, American Indian or Alaska Native, Native Hawaiian or other Pacific Islander), ethnicity (Hispanic or non-Hispanic), grade, height, weight, and participation in a variety of health behaviors, including those related to nutrition and physical activity.

BMI percentile, calculated from self-reported height and weight, was used as a measure of student adiposity. BMI percentile accounts for developmental differences between boys and girls of different ages by measuring each student's BMI relative to a reference population composed of children of the same age and sex in the U.S. from 1963-1994.[27] In 2000, the CDC conducted a study to assess the validity and reliability of self-reported height and weight in a sample of 2,965 high school students.[114] Students were asked to complete the 1999 YRBS questionnaire twice, two weeks apart, and then had their height and weight measured. The self-reported height and weight were highly reliable (Pearson $r > 0.90$), but students overreported their height by an average of 2.7 inches, and underreported their weight by 3.5 pounds. Both of these errors would make students' self-reported BMI lower than would be expected from direct measurements of height and weight.

The primary outcome of interest in Aim 1 was BMI percentile, rather than obesity, because weight gains in childhood have been associated with cardiovascular risk factors independent of weight classification.[115, 116] Furthermore, the 95th percentile of BMI is commonly used to define obesity among youth,[117] but Freedman et al. reported that the ability of this cut-point to identify youth of excess fatness varied by race/ethnicity, particularly among girls.[118]

Analyses of time trends included all nutrition and physical activity behaviors that were measured in every year from 2001 to 2007:

- Fruit consumption
- Green salad consumption
- Carrot consumption
- Potato consumption
- Other vegetable consumption
- 100% fruit juice consumption
- Milk consumption
- Television viewing
- PE enrollment

- Sports team participation

Soda consumption could not be included in the analyses of time trends because it was not measured in most states until 2007. Because of the increase in soda consumption that has taken place among youth in recent decades,[35-37] and the observational association between soda consumption and weight gain,[38, 39] Aim 2 focused on soda consumption as the primary outcome of interest in analyses of policy change.

All dietary consumption behaviors were measured by asking students to report the frequency at which they engaged in the behavior during the previous 7 days (e.g., “During the past 7 days, how many times did you eat fruit?”). Daily servings of fruit, salad, potatoes, carrots, and other vegetables were summed to create a measure of daily servings of fruits and vegetables. Television viewing was measured by the number of hours that students watch TV on an average school day. PE enrollment was measured by the number of days in an average week that they take PE when in school. Sports team participation was measured by asking students to report the number of teams they played on in the past 12 months.

YRBS was the optimal data source for this study because it is the only survey that has collected adolescent data on diet, physical activity, and adiposity that are representative of states across the country over multiple years. YRBS is also limited, however, by its reliance on self-report. Like height and weight, diet and physical activity behaviors are prone to measurement error among youth,[119, 120] and the reliability of some of the YRBS measures has been questioned. In two distinct studies of the same convenience sample, Rosenbaum[121] and Brener et al.[122] used different measures (tetrachoric correlation, TCC; kappa; standard error multiplier) to assess the reliability of YRBS measures of sports participation, PE attendance, and TV viewing. Results varied by measure, but generally indicated that PE attendance had strong reliability (TCC = 0.98, Kappa = 85%) and sports participation and TV viewing had moderate reliability (TCC = 0.77 and 0.68, respectively; Kappa = 56% and 47%, respectively). The reliability of diet behaviors was not assessed in either study.

School Health Policies and Programs Study

Survey design

SHPPS is a national study of school-based policies and programs related to eight health-related components, including Food Services.[123] Data were collected from nationally representative samples at four different levels of policy-making and implementation (state, district, school, and classroom) in 1994, 2000, and 2006. Aim 2 analyses utilized state-level data from 2000 and 2006, which were provided by all fifty states and the District of Columbia.

State-level data on Food Services policies were collected from personnel who were identified by the state education agency or department of health as being most knowledgeable about policies related to Food Services.[124] Data were collected using self-administered written questionnaires in 2000, and either self-administered written questionnaires or phone interviews conducted by trained interviewers in 2006. Following the 2000 SHPPS, Brener et al. studied the reliability and validity of data through interviews with respondents.[125] The authors generally did not discuss results for specific component areas, but reported that the survey produced valid data overall.

Variables

The primary analysis in Aim 2 focused on changes in policies that were measured in both 2000 and 2006. In both years, respondents were asked if the state required or recommended that schools be prohibited from offering junk foods in 8 different settings:

- Breakfast and lunch periods
- Student parties
- After-school or extended day programs
- Concession stands
- Vending machines
- School stores, canteens, or snack bars
- Staff meetings
- Meetings attended by students' family members

"Junk food" was defined in the 2000 survey as "foods that provide calories primarily through fats or added sugars and have minimal amounts of vitamins and minerals." The definition was slightly adapted in the 2006 survey to read, "foods or beverages that have low nutrient density, that is they provide calories primarily through fats or added sugars and have minimal amounts of vitamins and minerals." Participants could answer "require," "recommend," or "neither" for each of the 8 settings. Questions regarding staff meetings and meetings attended by family members were not included in Aim 2 on the rationale that students are not frequently exposed to these settings.

Data across settings were combined to create a more comprehensive policy measure. 'Neither' was coded as 1, 'recommend' as 2, 'require' as 3, and the 6 settings were summed to calculate a score for both 2000 and 2006. The difference between the 2006 score and 2000 score was used as a measure of overall policy change.

Several additional policies related to junk food were added to the survey in 2006. States were asked whether they require or recommend that schools: 1) restrict the times that soda, fruit drinks, or juice drinks can be sold, 2) restrict the times that junk food can be sold, 3) prohibit junk foods from being sold for fundraising purposes, 4) prohibit brand-name fast foods from being offered at school meals, and 5) prohibit advertising for soft drinks, candy, or fast food restaurants. The effects of these policies were estimated as part of a cross-sectional, secondary analysis.

Other data sources

As part of the social ecological framework, analyses included several contextual variables that may account for between-state differences in adolescent adiposity independent of the individual-level variables that were measured. Singh et al. found that state-level income inequality, poverty rate, and violent crime rate accounted for 16%, 18%, and 7% of the state disparities in youth obesity prevalence, respectively.[12] Aim 1 analyses incorporated these variables along with state cigarette taxes, which have been associated with adult BMI trends,[126-128] to determine if they account for state disparities in adolescent adiposity trends. Aim 2 analyses included variables that have been associated with state legislative activity targeting obesity – median income,[76] political party of the state legislature,[76, 77] and obesity prevalence[76, 78] – to obtain an unbiased estimate of the effect of state policies. Details of how these variables were used are provided in the next section. Poverty rate, median income, violent crime rate, and income inequality (as measured by the Gini coefficient) were obtained from the U.S. Census.[129] Data on cigarette taxes were obtained from the Tax Foundation.[130] Adult obesity prevalence was obtained was the Behavioral Risk Factor Surveillance System (BRFSS).[131] The state legislature political party following the 2000 election was obtained from the National Conference of State Legislatures.[132]

Statistical analysis

Overview

Students who live in the same state are likely to have similar behaviors and health patterns because they share a common social, cultural, economic, and political environment that distinguishes them from students in other states.[133] This is reflected in the geographic clustering of youth obesity.[12, 134] When within-state observations are correlated with each other, this violates a basic assumption of ordinary least squares regression that observations are independent. Ignoring such correlation can cause one to underestimate the variance of parameter estimates because one is ignoring the extra source of variation that states generate.[135] This leads to an inflated Type I error rate that can ultimately lead to erroneous conclusions.[135]

Mixed models account for this extra variation by explicitly modeling the state as a random effect. This can include a random intercept, which allows each state to have its own intercept in a regression model, or a random slope, which allows each state to have its own slope for any of the variables in the model. Mixed models are particularly advantageous when one is interested in estimating the variance associated with the state. The variance is often measured by the intraclass correlation coefficient (ICC), the proportion of the total variance that is attributable to the state.[133]

Measures of variance have been advocated as a means of studying the context in which disease takes place,[136] and are increasingly being viewed as a valuable complement to epidemiologic studies that focus on changes in a population mean. Conventional epidemiologic parameters, such as an odds ratio, are not appropriate in a study such as ours because the hypothesis is that there is no single odds ratio to represent the population. Measures of variance are also valuable to policymakers because health conditions and behaviors can cluster at many levels – neighborhoods, metropolitan areas, states, regions – and policies can likewise be enacted at many levels – classrooms, schools, districts, states, country. Obesity policies have more potential to reduce obesity on a population level if they are enacted on the ecologic level at which obesity tends to cluster, and only if they target behaviors that cluster on the same level.

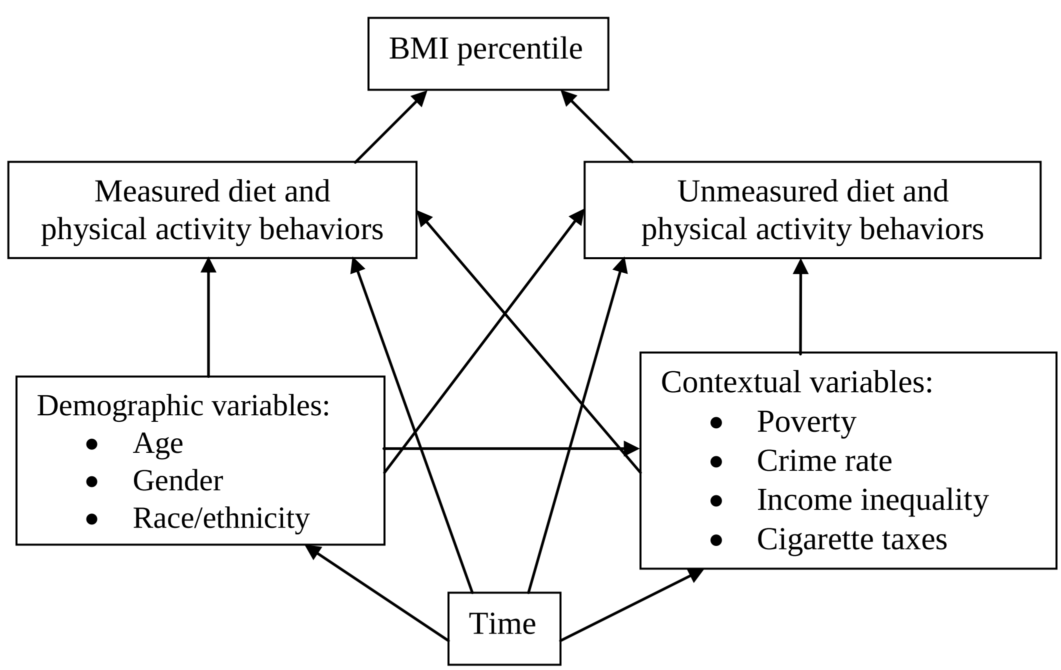
There are other statistical methods that can account for geographic clustering, including generalized estimating equations (GEE)[137] or robust variance estimates.[138] These methods are appropriate when one needs to adjust for correlated data, but is not interested in explicitly quantifying the variance. Robust variance estimates, for example, are used for parts of Aim 1 that were focused on computing estimates of the sample mean and simply wanted to adjust for state clustering (described in more detail below.)

Throughout both Aims, analyses of student-level data accounted for the YRBSS sample design. Mixed model analyses were conducted with Mplus Version 5.21 to incorporate the sampling weights in the YRBS.[139] All other analyses were conducted with Stata 11.[140]

Aim 1

The conceptual framework in Figure 4 guided analyses of time trends. The term "time trend" refers here to the average change in BMI between survey years (2001 to 203, 2003 to 2005, etc.) The primary objective of Aim 1 was to estimate state variation in time trends that took place from 2001 to 2007. The goal was to model actual trends during this period, not adjusted trends. If states have different trends because of different racial distributions, for example, this does not change the fact that there are state disparities in BMI trends over time. Consequently, models in which time was the independent variable of interest did not adjust for any covariates. After estimating time trends and state variation in these trends, however, supplementary analyses were conducted to decompose the variation in an effort to identify variables that have distinguished states with different trends. These steps are described in more detail below.

Figure 4. Analytic framework for analyses of time trends



Variables of interest were conceptually broken down into 3 categories: behavioral, demographic, and contextual. The underlying assumption of Aim 1 is that changes in BMI percentile over time are directly caused by changes in diet and physical activity behaviors. This includes behaviors measured in YRBS as well as unmeasured behaviors (e.g., video game use). Demographic and contextual changes were examined as a means of controlling for unmeasured behaviors. Crime rate, for example, has been associated with video game use[141] and physical activity,[142] variables that could not be included in Aim 1 because they were not measured in YRBS consistently over time. Crime rate and other contextual variables are essentially used as proxies for behaviors not included in YRBS. Demographic variables can likewise influence BMI through age, gender, and racial/ethnic differences in measured and unmeasured behaviors. Analyzing within-state demographic changes is important to ensure that any BMI percentile changes over time are not simply due to demographic shifts within states, as described in the Introduction.

Aim 1 began with pooling data from the 2001, 2003, 2005, and 2007 YRBS into a single data set. Care was taken to ensure that all variables of interest were measured consistently across states and across years. Any minor discrepancies resulted in a state or variable being excluded from the analysis.

The analyses of time trends in BMI percentile and weight-related behaviors had four distinct analytic components:

Aim 1a: To estimate the time trend in BMI percentile and all weight-related behaviors in the sample overall.

Aim 1b: To estimate the cross-sectional association between weight-related behaviors and BMI percentile

Aim 1c: To estimate between-state variation in time trends of BMI percentile and weight-related behaviors

Aim 1d: To compare states with disparate time trends in BMI percentile with respect to changes in behavioral, demographic, and contextual variables

Aim 1a

A linear model with robust standard error was used to estimate the time trend in BMI percentile and weight-related behaviors in the sample overall.[138] The model of BMI percentile trends also tested for an interaction between gender and year ($\alpha = 0.10$) and found that it was significant. Subsequently, all analyses were stratified by gender. Interactions between race/ethnicity and year were not explored because the primary purpose of Aim 1 was to estimate state variation in time trends, and several states did not have enough racial/ethnic diversity to accurately estimate within-state time trends by race/ethnicity. After stratifying by gender, non-linear time trends were explored by including a quadratic term for time in both gender groups ($\alpha = 0.10$). Only those that were statistically significant were retained.

These analyses focused on BMI percentile as a measure of adiposity for the reasons described earlier. However, to facilitate comparisons of our results with Ogden et al., who focused on obesity,[10] analyses of overall time trends were repeated using obesity as the outcome.

Aim 1b

Similarly, a linear model with robust standard error was used to estimate the associations between behavioral variables and BMI percentile. All behaviors were modeled simultaneously and adjusted for race/ethnicity, age, and state-level measures of poverty, crime rate, income inequality, and cigarette taxes. To facilitate the interpretation of results, behaviors were modeled with a small number of categories to create a parsimonious model. Categories were chosen using a mixture of bivariate dose-response analyses (Appendix A) and conventional public health recommendations (e.g., 5 or more fruits and vegetables per day). Juice consumption and TV viewing were modeled as continuous variables, and the following behaviors were dichotomized: sports (≥1 per 12 months), PE attendance (≥1 day per week), fruit/vegetable consumption (≥5 per day), and milk consumption (≥4 glasses per day).

Aim 1c.

Linear mixed models were used to estimate between-state variance in the time trends of BMI percentile and weight-related behaviors. The notation for the mixed models is adapted from Murray.[135] BMI percentile is used as an example, but identical models were used to estimate time trends in each weight-related behavior. For this part of the analysis, all variables were modeled as continuous outcomes:

$$\mathrm{BMI}_{i:jk} = ß_0 + T_{(lin)}t_k + \mathbf{S_j} + \mathbf{S_j}\,\mathbf{T_{(lin)}}t_k + \boldsymbol{\varepsilon_{i:jk}}$$

$BMI_{i:jk}$ represents the BMI percentile of the *i*th individual nested within state *j* in year *k*. Mixed models account for state clustering by estimating an overall intercept, $ß_0$, as well as a random intercept ($\mathbf{S_j}$) by state, ~ N (0, σ^2_s). The overall intercept can be interpreted as the mean state-level BMI percentile in 2001. $T_{(lin)}t_k$ represents the linear time trend, or the average change in mean BMI percentile per year across states. $\mathbf{S_j}\, \mathbf{T_{(lin)}}t_k$, ~ N (0, $\sigma^2_{t(lin)s}$), represents a random slope for time by state. Due to the non-linearity of BMI percentile among girls, another random component ($\mathbf{S_j}\, \mathbf{T_{(quad)}}t_k^2$) was added to estimate the variance of the quadratic component of the estimated time trend in BMI percentile among girls. The ICC for the intercept and linear component of the time trend was calculated in boys and girls, along with the ICC for the quadratic component among girls. All random parameters were allowed to covary in an effort to determine if, for example, states with a higher mean BMI percentile in 2001 had a larger or smaller increase in BMI percentile from 2001 to 2007.

Aim 1d.

After estimating between-state variance, a case-control design was used to explore differences between states in which BMI percentile increased between survey years and those in which it decreased. This involved creating a data set in which state was the unit of analysis and each 2-year survey interval (i.e., 2001-03, 2003-05, 2005-07) was a separate observation. States thereby appeared in the data set 3 times if data were collected in each survey year. Four-year intervals (e.g., 2001-05) were not included. Each observation was categorized according to whether the BMI percentile increased or decreased during that interval in that state. T-tests ($\alpha = 0.10$) were used to compare state/interval observations in which BMI percentile increased to those in which it decreased – analogous to a case-control analysis – with respect to changes in demographic, behavioral, and contextual variables during the same interval. As a sensitivity analysis, the test was repeated after limiting the sample to states that increased or decrease by a magnitude of 0.5 BMI percentile units. Results from the sensitivity analyses are provided in Appendix B.

Aim 2

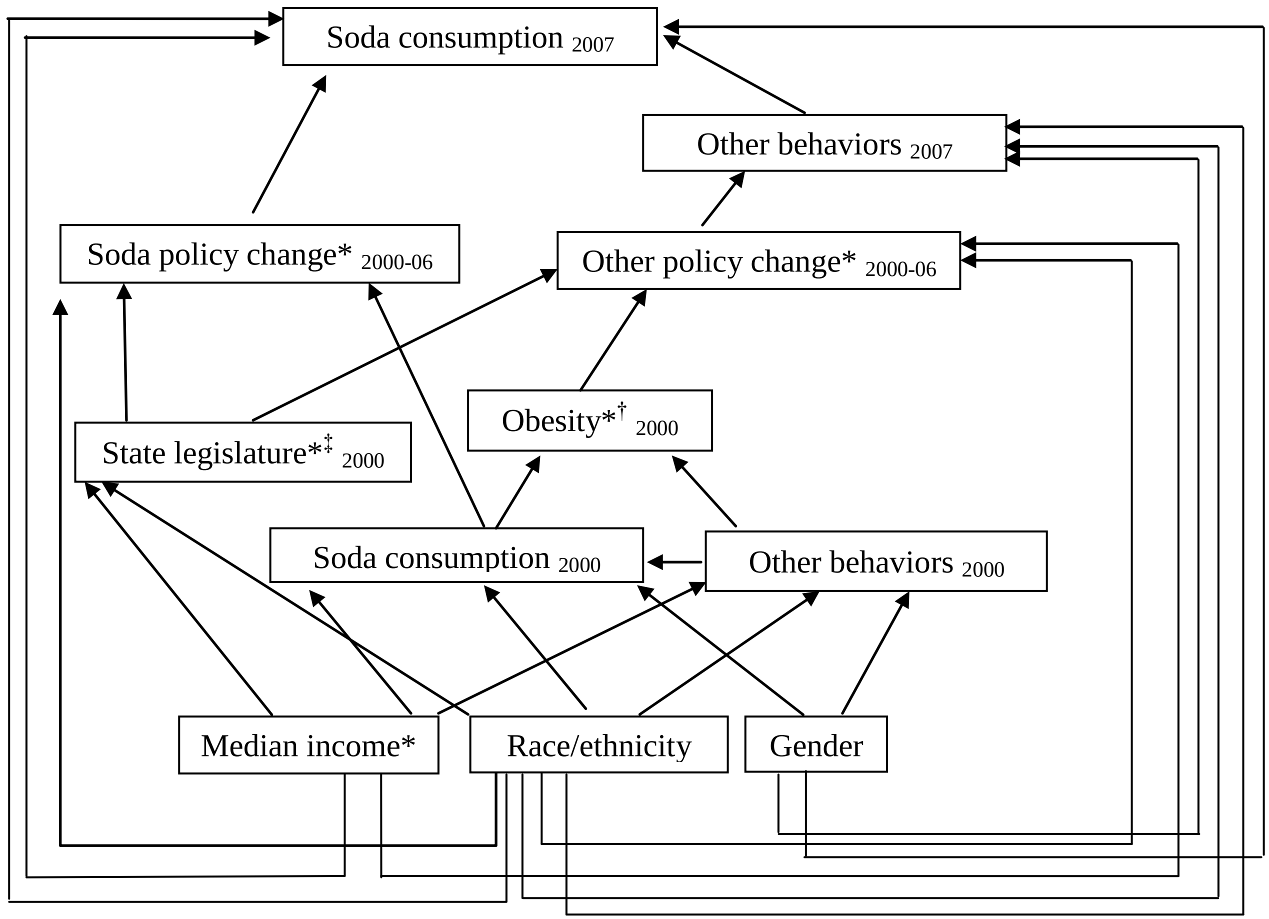
Aim 2 began with examining the distributions of state policies in 2000 and 2006 to determine the optimal way to model policy change. Policies were highly skewed in 2000, with all but a few states reporting that they ‘neither’ recommend nor require schools to prohibit junk foods. Thus, most analyses were restricted to states that reported ‘neither’ in 2000, and models estimated the association between 2006 policy and 2007 soda consumption (as measured by daily servings of soda.) By using the states that reported ‘neither’ in 2000 as the study population, the coefficients for 2006 policy effectively represented the association between policy change and soda consumption.

This association was estimated using a generalized linear mixed model with a random intercept to account for state clustering. Though soda is listed as the outcome of interest below, all analyses were repeated using BMI percentile as the outcome:

$$Soda_{i:j} = ß_0 + ß_1(2006\ policy) + ß_x X + \mathbf{S_j} + \boldsymbol{\varepsilon_{i:jk}}$$

X represents all student- and state-level covariates, which were selected using the directed acyclic graph (DAG) in Figure 5. The DAG illustrates how the association between junk food policy change and soda consumption can be confounded by changes in other types of policy. States have taken substantial legislative action to reduce obesity, proposing and enacting many types of policies that target behaviors other than soda consumption (e.g., PE requirements). Soda consumption may indirectly be affected by policies aside from the ones in Aim 2 unless steps are taken to control for variables that motivate other types of policy change. State median income,[76] political party of the state legislature,[76, 77] and obesity prevalence,[76, 78] have been associated with legislative activity targeting obesity. These variables, along with gender and race/ethnicity, were identified as covariates necessary to obtain an unbiased estimate of the effect of policy change on soda consumption, on the basis of Figure 5.[143, 144] Data from the year 2000 were used for all state-level variables to ensure that the variables were measured prior to policy change.

Figure 5. Directed acyclic graph (DAG) representing the effect of soda policy change on soda consumption



* State-level measure

† Adult obesity prevalence

‡ Whether state legislature is controlled by Democratic party

Modification by race/ethnicity

After estimating the overall association between policy change and soda consumption for each policy measure, the next step was to test for differences in the association across racial/ethnic groups. The model was repeated after adding an interaction term between 2006 policy and each racial/ethnic group except non-Hispanic Whites, and a likelihood ratio test was used to determine if the overall interaction between race/ethnicity and policy was statistically significant ($\alpha = 0.05$, df = 3). The association between policy change and soda consumption was calculated in each group by adding the appropriate coefficients. The results in the second manuscript present these racial/ethnic-specific associations, but the differences between the association in non-Hispanic Whites and each racial/ethnic minority, and the standard errors of the differences, are presented in Appendix C. The difference between racial/ethnic groups in the association between policy change and BMI percentile was also calculated and is presented in Appendix D.

Supplementary analyses

Two supplementary analyses are included in the Appendices: a sensitivity analysis in which the association between policy change and BMI percentile corrected for measurement error in self-reported height and weight (Appendix E), and a cross-sectional analysis of policies that were measured only in 2006 (Appendix F). The sensitivity analysis adjusted for measurement error by adding 3.5 pounds and subtracting 2.7 inches from each student's self-reported measures. These were the mean errors reported by Brener et al. in their validity study of self-reported height and weight in YRBS.[114] The analysis of 2006 policies used the same statistical methods as analyses of policy change.

State disparities in time trends of adolescent adiposity and weight-related behaviors

ABSTRACT

Background

The prevalence of youth obesity in the United States did not increase from 1999 to 2006. Legislation targeting youth obesity varied across states within this period, and obesity is known to cluster by state. This led us to examine if adolescent adiposity time trends varied across states from 2001 to 2007, in boys and girls separately.

Methods

A time series design combined cross-sectional Youth Risk Behavior Survey data from 272,044 adolescents in 29 states from 2001 to 2007. Self-reported height, weight, sports participation, physical education, television viewing, and daily consumption of 100% fruit juice, milk, and fruits and vegetables were collected. Linear mixed models estimated state variance in time trends of behaviors and body mass index (BMI) percentile, as measured by the intraclass correlation for time (ICC_T).

Results

BMI percentile time trends were consistent across states, particularly in boys (ICC_T <0.00001). Boys experienced a modest linear increase (ß = 0.18, 95%CI: 0.07, 0.30) and girls experienced a non-linear increase that suggested a decelerating trend ($ß_{linear}$ = 1.10, $ß_{quad}$ = -0.08). States in which BMI percentile decreased experienced a greater decrease in TV

viewing than states where BMI percentile increased. Otherwise, states with disparate adiposity trends did not differ with respect to behaviors.

Conclusions

Adolescent adiposity continued to increase across states from 2001 to 2007. Behaviors that have been targeted by state legislation do not statistically account for these trends. Future research should explore the role of other behaviors (e.g., soda consumption), measurement units (e.g., portion size), and societal trends (e.g., urban sprawl).

BACKGROUND

Obesity has severe physical, psychosocial, and economic consequences during childhood and across the lifespan. Effects at an early age include type 2 diabetes, hypertension, dyslipidemia, sleep apnea, negative body image, low self-esteem, and depressive symptoms.[19] Obesity during childhood also tends to track into adulthood,[19] during which it is associated with cardiovascular disease, diabetes, several types of cancer, sleep disorders, and all-cause mortality.[20] As the U.S. population ages, the long-term effects of youth obesity are likely to become a greater public health burden. Using data on adolescent obesity in 2000 and historical trends of obesity tracking into adulthood, Bibbins-Domingo et al. projected that coronary heart disease prevalence in the U.S. will increase 5-16% by 2035 as a result of obesity among today's adolescents, resulting in an increase of 100,000 prevalent cases.[23]

Adolescent obesity became a pressing public health concern in recent decades as the prevalence increased from 5% in 1976-80 to 16% in 1999-2000.[1] However, a recent study by Ogden et al. reported no change from 2003 to 2006 and no trend across two-year periods from 1999 to 2006.[10] For that study, data were from the National Health and Nutrition Examination Survey (NHANES), which was designed to be representative of the United States, but not of individual states.[145]

Two recent reports from the 2003 National Survey of Children's Health (NSCH) indicated that there are state disparities in obesity among 10-17 year-old youth.[12, 134] The unadjusted prevalence of youth obesity ranged from 9% (Utah) to 23% (Washington D.C.), and 25 states had elevated odds of obesity, relative to Utah, after accounting for compositional differences in age, gender, race, and socioeconomic status.[12] Geographic disparities in obesity are a common finding worldwide, as studies in Canada,[100] Austria,[101] Australia,[102] England,[103] Scotland,[104] India,[105] and France[106] found that obesity tends to cluster by state, province, or other geographic region. The authors of one of the NSCH studies recommended further exploration of geographic disparities in trends of youth obesity over time,[134] which has not been done in the U.S. to our knowledge.

Recent state-level trends are particularly relevant because states have implemented many policies and programs to combat obesity.[9] In 2003-05, state legislatures proposed 717 bills and 134 resolutions related to youth obesity, and adopted 123 and 71 of them, respectively.[9] Legislation targeted areas such as physical education (PE) requirements, access to school vending machines, and appropriations for farmers markets and walking or biking trails. The increase in legislative activity took place within the same period in which Ogden et al. described a "plateau" in youth obesity nationwide.[10] Legislative activity varied across states, as the total number of bills and resolutions ranged from 0 (Wyoming) to 63 (Illinois), and the proportion of legislation that was adopted varied from 0% (several states) to 80% (Nevada) from 2003 to 2005.[9]

This variation in legislative activity across states led us to hypothesize that states experienced different trends in youth adiposity from 2001 through 2007. Because Ogden et al.'s analyses were based on a nationwide sample,[10] it cannot be assumed that the plateau can be particularized to all states. Two of the goals of *Healthy People 2010* were to reduce obesity overall and reduce geographic disparities,[18] but such disparities could be worsening if the observed plateau in youth obesity in the U.S. is due to increases in some states countered with decreases in others.

The primary objective of this study was thus to estimate state variation in time trends of adolescent adiposity and weight-related behaviors from 2001 to 2007, in boys and girls separately. We also compared states in which adolescent adiposity increased to those in which it decreased during this time period, to identify behavioral, demographic, and contextual factors that distinguish states with different trends. Identifying and comparing states with disparate trends can help policymakers by identifying factors that distinguish states that reversed or attenuated the trends in youth obesity from those that did not.

METHODS

Sample

The time-series design combined cross-sectional samples from the 2001, 2003, 2005, and 2007 state Youth Risk Behavior Survey (YRBS), a biennial survey of 9^{th}-12^{th} grade students, administered on the national, state, and local level. Participation by states was voluntary in each year. Students were sampled by the state using a two-stage cluster sampling design, and data were weighted according to school and student response rates to produce estimates that are representative of the state jurisdiction.[109] Data were weighted only in states that provide appropriate documentation and have an overall response rate ≥ 60%. Years in which states did not fit these criteria were excluded from analyses because their data were not considered representative. We further limited analyses to states that provided height and weight data in 3 survey years (n=15: AL, AZ, AR, DC, GA, IN, KY, MS, NH, NY, OH, TN, TX, VT, WV) or 4 survey years (n=14: DE, FL, ID, MA, ME, MI, MO, MT, NC, ND, RI, UT, WI, WY) from 2001 to 2007. A total of 272,044 students from these 29 states provided data in 2001, 2003, 2005, and 2007 combined. Individual students were not followed over time.

Variables

Anthropometric and behavioral data

Data were collected using a written questionnaire administered in class. Our outcome of interest was body mass index (BMI) percentile, calculated from self-reported height and weight. BMI percentile accounts for developmental differences between boys and girls of different ages by measuring each student's BMI relative to a reference population composed of children of the same age and sex in the U.S. from 1963-1994.[27] Brener et al. studied the validity of self-reported height and weight data and found that students overreported their height by an average of 2.7 inches and underreported their weight by 3.5 pounds, but the correlations with measured height and weight were 0.90 and 0.93, respectively.[114]

We focused on trends in BMI percentile rather than obesity because weight gains in childhood have been associated with cardiovascular risk factors independent of weight classification.[115, 116] The 95th percentile of BMI is commonly used to define obesity among youth,[117] but Freedman et al. reported that the ability of this cut-point to identify youth of excess fatness varied by race/ethnicity, particularly among girls.[118] However, to facilitate comparisons of our results with Ogden et al., who focused on obesity,[10] we repeated the analyses of time trends using obesity as the outcome.

Our analyses included all nutrition and physical activity behaviors (referred to collectively as "weight-related behaviors") that were measured in the majority of states in each survey year from 2001 to 2007: sports played in the past 12 months, days of PE per school week, hours of television (TV) watched per school day, and daily consumption of 100% fruit juice, fruit, salad, potatoes, carrots, other vegetables, and milk. Daily servings of fruit, salad, potatoes, carrots, and other vegetables were summed to create a measure of fruit and vegetables per day. All behaviors were hypothesized to be negatively associated with BMI percentile except TV viewing, which was hypothesized to be positively associated.

Demographic variables

The demographic variables of interest were self-reported age, gender, and a 4-category measure of race and ethnicity: non-Hispanic White, non-Hispanic Black, Hispanic, and non-Hispanic Other.

Contextual variables

Singh et al. found that state-level poverty rate, income equality, and violent crime rate statistically accounted for 17%, 16%, and 7% of the state variance in youth obesity, independent of individual-level behavioral and demographic variables.[12] We obtained data on these variables over time to determine if they were similarly associated with BMI percentile trends. State-level data on household income inequality, as measured by the Gini coefficient, was obtained for each survey year from the U.S. Census, as were poverty rate and violent crime rate.[129]

Multiple studies have examined the impact of cigarette prices and taxes on adult BMI trends, with two studies finding a positive association[126, 127] while Gruber and Frakes found a negative association.[128] This topic has not been explored in adolescents to our knowledge. Given that youth are responsive to changes in cigarette prices,[146] we examined whether state-level changes in cigarette taxes were associated with state BMI percentile trends, using data from the Tax Foundation.[130]

Statistical analyses

All analyses accounted for the complex sample design in YRBS.[109] As a preliminary analysis, we estimated the time trend in BMI percentile and all weight-related behaviors in the sample overall. We used a linear model with a robust standard error to account for state clustering in this part of the analysis.[138] In the model of BMI percentile trends, we tested for an interaction between gender and year ($\alpha = 0.10$) and found that it was significant. Subsequently, all analyses were stratified by gender. We chose not to test for an interaction between race/ethnicity and year because the primary purpose of this study was to estimate state disparities, and several states did not have enough racial/ethnic diversity to accurately estimate within-state time trends by race/ethnicity. After stratifying by gender, we tested for non-linear time trends by including a quadratic term for time in both gender groups ($\alpha = 0.10$), and found that it was significant only for BMI percentile among girls.

Subsequently, we used a linear model with robust standard errors to estimate the associations between behavioral variables and BMI percentile. Models adjusted for race/ethnicity, age, and all contextual variables. Juice consumption and TV viewing were modeled as continuous variables, and the following behaviors were dichotomized: sports (≥1 per 12 months), PE attendance (≥1 day per week), fruit/vegetable consumption (≥5 per day), and milk consumption (≥4 glasses per day).

Linear mixed models were used to estimate variance in the time trends of BMI percentile and weight-related behaviors across states. The notation for the mixed models is adapted from Murray.[135] BMI percentile is used as an example, but identical models were used to estimate time trends in each weight-related behavior. For this part of the analysis, all variables were modeled as continuous outcomes:

$$\mathrm{BMI}_{i:jk} = ß_0 + T_{(lin)}t_k + \mathbf{S_j} + \mathbf{S_j}\,\mathbf{T_{(lin)}}t_k + \boldsymbol{\varepsilon_{i:jk}}$$

$\mathrm{BMI}_{i:jk}$ represents the BMI percentile of the *i*th individual nested within state *j* in year *k*. Mixed models account for state clustering by estimating an overall intercept, $ß_0$, as well as a random intercept ($\mathbf{S_j}$) by state, ~ N (0, σ^2_s). The overall intercept can be interpreted as the mean state-level BMI percentile in 2001. $T_{(lin)}t_k$ represents the linear time trend, or the average change in mean BMI percentile per year across states. $\mathbf{S_j}\,\mathbf{T_{(lin)}}t_k$, ~ N (0, $\sigma^2_{t(lin)s}$), represents a random slope for time by state. Due to the non-linearity of BMI percentile among girls, we added another random component ($\mathbf{S_j}\,\mathbf{T_{(quad)}}t_k^2$) to estimate the variance of the quadratic component of the estimated time trend in BMI percentile among girls. We calculated the intraclass correlation (ICC) for the intercept and linear component of the time trend in boys and girls, as well as the ICC for the quadratic component among girls. The ICC represents the proportion of variance in BMI percentile due to state differences in each parameter. All random parameters were allowed to covary, allowing us to determine if, for example, states with a higher mean BMI percentile in 2001 had a larger or smaller increase in BMI percentile from 2001 to 2007. Mixed model analyses were conducted with Mplus Version 5.21 to incorporate the sampling weights in the YRBS.[139] All other analyses were conducted with Stata 11.[140]

After estimating between-state variance, we explored differences between states in which BMI percentile increased between survey years and those in which it decreased. We created a data set in which state was the unit of analysis and each 2-year survey interval (i.e., 2001-03, 2003-05, 2005-07) was a separate observation, meaning states would appear in the data set 3 times if data were collected in each survey year. Four-year intervals (e.g., 2001-05) were not included. Each observation was categorized according to whether the BMI percentile increased or decreased during that interval in that state. We used t-tests ($\alpha = 0.10$) to compare state/interval observations in which BMI percentile increased to those in which it decreased – analogous to a case-control analysis – with respect to changes in demographic, behavioral, and contextual variables during the same interval.

RESULTS

Descriptive statistics

Table 5 provides the sample size, mean BMI percentile, obesity prevalence, and distribution of demographic variables overall, and descriptive statistics of state participation and within-state sample size and student response rates. BMI percentile and prevalence of obesity, as defined by the 95^{th} percentile of BMI,[117] both increased across years. Across states, the mean BMI percentile in 2001 ranged from 52.7 in Utah to 65.5 in Washington D.C. BMI percentile clustered by region, as most states in the Southeast had a mean percentile above the sample median, while all states in the Rocky Mountain region had a mean percentile below the median.

Estimated trends in BMI percentile and weight-related behaviors

Table 6 displays the estimated 2001 mean and time trends in BMI percentile and weight-related behaviors, by gender. The mean BMI percentile in 2001 was 57.67 and 63.57 among girls and boys, respectively. Among boys, the mean increased modestly over time, by

0.18 units per year. Among girls, the linear and quadratic coefficients for time (1.10 and -0.08, respectively) suggested that the mean BMI percentile increased throughout the study time period, but the magnitude of increase declined over time. Analyses of obesity trends (not shown) showed an increase over time among girls (OR for 1-year change: 1.04, 95% confidence interval: 1.02, 1.06), but no change among boys. TV viewing, milk consumption, and fruit juice consumption decreased across years in both genders, but the change per year was <0.05 units. Milk consumption, for example, decreased each year by 0.02 glasses per day among girls, or 1.7% of the 2001 mean. PE attendance, sports participation, and fruit and vegetable consumption did not change over time in either group.

Associations between BMI percentile and weight-related behaviors

Cross-sectional associations between each behavior and BMI percentile are displayed in Table 7. TV viewing was the only behavior that was associated with BMI percentile in the hypothesized directions among both boys and girls. Playing at least one sport was negatively associated among girls, but positively associated among boys. Greater juice consumption was also associated with lower BMI percentile among girls. Among boys, higher BMI percentile was associated with drinking 4 or more glasses of milk per day or having at least 1 day of PE per week. Other estimates were close to the null.

Between-state variance in trends

Though the behavioral changes over time were small overall, Figure 6 shows that time trends in most behaviors varied by state in magnitude and even in direction. Each line represents the time trend among girls for a different state, as estimated by the mixed model.

Graphs of state trends among boys were qualitatively similar, and the intraclass correlations for both genders are displayed in Table 8. Even though the proportion of variance attributable to state differences in time trends was low for each behavior ($ICC_T < 0.1\%$), Figure 6 shows a heterogeneous combination of state trends in fruit and vegetable consumption, sports participation, and PE attendance. For each behavior, some states experienced an increase over time while others experienced a decrease. All states experienced a decrease in milk and fruit juice consumption among girls, and the range of decline was small (0.01 – 0.03 daily servings of milk; <0.01 – 0.04 daily servings of juice.) State trends were negatively correlated with their 2001 mean ($r_{\beta 0, \beta T}$) for each behavior, indicating that states with a lower mean in 2001 had a greater increase over time. ICC_0 estimates indicate that, overall, state differences accounted for 1-2% of the variance in sports participation, fruit and vegetable consumption, and fruit juice consumption in both genders, as well as PE attendance in boys, and 5-7% of the variance in TV viewing and milk consumption, and PE attendance in girls.

In contrast to Figure 6, the state variance in BMI percentile time trends was very low (Figure 7), particularly among boys ($ICC_T = 0.0008\%$). State trends among boys were negatively correlated with 2001 means ($r = -0.95$). The ICC_T was higher for girls, but the shape of the trend was very similar across states. BMI percentile increased from 2001 to 2007 among girls in all states, but the rate of increase generally declined over time.

Case-control analysis

Table 9 displays the results of the state-level case-control analysis. TV viewing was the only variable that distinguished states in which BMI percentile increased from those in which it decreased in both boys and girls. During two-year YRBS intervals in which states experienced a decrease in BMI percentile (n = 19 and 26 in girls and boys, respectively), there was a greater decline in hours of TV per school day compared to intervals in which states experienced an increase in BMI percentile (n = 49 and 42, respectively). Changes in cigarette taxes, juice consumption, and the distribution of race/ethnicity also differed across categories of states among girls. During survey intervals in which within-state BMI percentile decreased, there a smaller decline in the proportion of non-Hispanic Whites and a decline in the proportion of non-Hispanic Blacks, while among intervals in which within-state BMI percentile increased, there was an increase in non-Hispanic Blacks. The mean increase in taxes was nearly two times as high among intervals in which within-state BMI percentile decreased among girls, and the decrease in fruit juice consumption was greater.

DISCUSSION

Adiposity changes over time were similar across states even though states experienced different trends in weight-related behaviors. These results are not contradictory given that both the behavioral trends and the association between the behaviors and BMI percentile were modest in size. Sports participation among girls, for example, had a relatively high association with BMI percentile, but its prevalence was stagnant from 2001 to 2007 and the change in prevalence did not differ between states with different BMI percentile trends. Among girls, differences in BMI percentile between states may be attributable to demographic shifts in the racial distribution more than behavioral changes. The behavioral trends and associations between behaviors and BMI percentile may have been attenuated by measurement error or unmeasured confounding, but they suggest that the measured behaviors do not account for recent BMI percentile trends.

TV viewing was the only behavior that was associated with BMI percentile on both the student and state level in our analysis. The positive association on the student level, coupled with the decline in TV viewing, might seem to contradict the overall increase in adiposity. However, TV viewing declined primarily in states in which BMI percentile decreased, suggesting that the decline may partially account for the decelerating BMI percentile trend overall. TV viewing also had the highest overall ICC of any behavior, implying that it may be influenced by state-level factors. Future research could explore state-level determinants of TV viewing, and also explore if adolescents have replaced TV viewing with alternative pursuits that are more active or sedentary (e.g., computers, phone).

The lack of state variance in adiposity trends is interesting given that legislative activity to reduce childhood obesity has varied considerably across states.[9] Arkansas has been particularly aggressive in removing vending machines from schools and requiring that students' BMI be measured and results confidentially mailed to parents; after the legislation was passed in 2003, researchers reported that obesity did not increase in Arkansas between the 2003-04 and 2004-05 school years.[147] However, these findings must be considered in light of the fact that Arkansas had the 2nd-highest BMI percentile among states in our sample in 2001. Given that populations with a higher BMI percentile at baseline experienced less adiposity gain (e.g., boys; states with a higher BMI percentile in 2001), Arkansas' stability may be attributable to a nationwide pattern of high-adiposity populations reaching a plateau. States with similar BMI percentile distributions at baseline would need to be compared to support the causal effect of legislative changes.

In contrast to the plateau in youth obesity that was found by Ogden et al. using NHANES data,[10] we found that adiposity among adolescents increased from 2001 to 2007 according to self-reported YRBS data. The increase was more pronounced among girls, who had a lower BMI percentile at baseline compared to boys. The gender gap declined from 5.9 BMI percentile units in 2001 to 3.3 in 2007, but the increase among girls appeared to decelerate over time and their rate of increase was similar to boys by 2005-2007. State disparities shrank modestly over time among boys, as states that had a lower BMI percentile among boys in 2001 experienced a greater increase over time. Collectively, these patterns of convergence suggest that increases in adolescent adiposity in the U.S. in recent years have primarily occurred in populations that have historically had a lower BMI percentile.

For this reason, Ogden et al. may have found no change in obesity prevalence in NHANES because they were testing for changes in the upper end of the BMI percentile distribution.[10] Increases in adolescent adiposity in the U.S. may be occurring primarily below the overweight/obesity cut-points. We found no increase in obesity over time among boys, though we did find an increase in obesity among girls. The discrepancy between our results and those of Ogden et al. could also be due to different samples: NHANES sampled a wider age range (2-19 yrs) and is designed to represent the U.S. as a whole,[145] while the state YRBS is designed to represent 9th-12th grade students in individual states. Finally, NHANES measures height and weight directly while YRBS relies on self-report, which is prone to measurement error.[114] We likely underestimated adiposity, but this would not create a bias toward detecting a time trend unless measurement error decreased over time. It is conceivable that measurement error changed over time due to the increasing focus on youth obesity in the U.S., which may have made students more conscious of their weight. This would suggest that measurement error increased over time, however, which would only lead us to underestimate the trend.

In addition to being limited to self-reported height and weight, our analyses were limited to self-reported behaviors that are also prone to measurement error.[119, 120] Non-differential error may have caused us to underestimate the association between these behaviors and BMI percentile. Our study was also limited to the 29 states that provided representative data in enough survey years during the study period. Results cannot be generalized to other states, and we were unable to estimate state variation in time trends by race/ethnicity because of the limited sample. Finally, our analyses were based on a series of cross-sectional surveys, so we were unable to examine within-student changes over time or assess causality between weight-related behaviors and BMI percentile.

Many societal trends that we did not examine have been hypothesized to contribute to the contemporary "obesogenic" environment, such as increased portion sizes,[46] urban sprawl,[47] and growth of the processed food sector.[44] These trends may impact other behaviors such as soda consumption, which the YRBS did not measure until 2007, or measurement units that are not captured by YRBS (e.g., portion size). Future research should explore if such trends have contributed to recent increases in youth adiposity.

Our study was strengthened by using multiple years of data designed to be representative of individual states. The sampling design of YRBS and sample size of our analysis provide evidence that adolescent adiposity in the U.S. has not peaked even if youth obesity prevalence is no longer increasing.[10] National, state, and local health organizations should continue to monitor adiposity patterns to determine if sub-groups with a lower BMI percentile are continuing to gain weight. The lack of increase in BMI percentile in states such as Arkansas is encouraging, but rigorous studies are needed to determine if legislative action is a cause of the stability, so that states in which adiposity continues to increase can apply effective methods to alleviate the trend.

TABLES & FIGURES

Table 5. Unweighted descriptive statistics of samples from 29 states that participated in Youth Risk Behavior Survey (YRBS) in at least 3 years, 2001-2007

	2001	2003	2005	2007
Sample size (students)	53,292	60,114	76,342	82,296
Anthropometric variables				
BMI percentile (mean)	60.3	61.1	62.5	62.6
Obesity (%)	10.6	11.4	11.9	12.5
Demographic variables (%)				
Gender				
Male	50.7	51.2	51.2	50.9
Female	49.3	48.8	48.8	49.1
Age				
≤14	10.7	11.6	12.1	11.1
15	26.6	26.8	27.1	26.5
16	27.2	26.8	27.0	27.2
17	22.2	21.9	22.2	23.3
≥18	13.3	12.9	11.6	11.9
Race/ethnicity				
Non-Hispanic White	67.3	63.9	62.2	61.1
Non-Hispanic Black	14.0	15.1	15.1	14.5
Hispanic	11.2	11.0	13.5	15.7
Non-Hispanic Other	7.5	10.0	9.3	8.7
State participation				
# of states that participated	19	26	28	28
Within-state sample size (students)				
Median	2,120	1,781	2,375.5	2,398
Minimum	1,071	1,088	1,140	1,324
Maximum	7,067	9,320	9,708	13,439
Within-state student response rate*				
Mean	81.2	82.2	78.8	78.1
Minimum	69	64	68	69
Maximum	90	94	92	89

* Student response rate = (number of useable questionnaires / number of students sampled)

Table 6. Estimated 2001 mean and time trends ($ß_T$) of BMI percentile and weight-related behaviors in the United States, by gender, Youth Risk Behavior Survey, 2001-2007

	Mean*	**SEM**	**$ß_T$**	**SE**
BMI percentile				
Girls	57.67	0.43		
Linear			1.10	0.19
Quadratic			-0.08	0.03
Boys	63.57	0.30	0.18	0.06
TV viewing				
Girls	2.07	0.03	-0.01	0.01
Boys	2.30	0.03	-0.04	0.01
Sports participation				
Girls	0.87	0.02	0.00	<0.01
Boys	1.18	0.01	0.00	<0.01
PE attendance				
Girls	1.68	0.05	0.01	0.02
Boys	2.17	0.04	0.01	0.01
Fruits and vegetables				
Girls	2.28	0.03	0.00	0.01
Boys	2.50	0.03	0.00	0.01
100% fruit juice				
Girls	0.86	0.01	-0.02	<0.01
Boys	1.01	0.01	-0.02	0.01
Milk				
Girls	0.91	0.01	-0.02	<0.01
Boys	1.42	0.02	-0.03	0.01

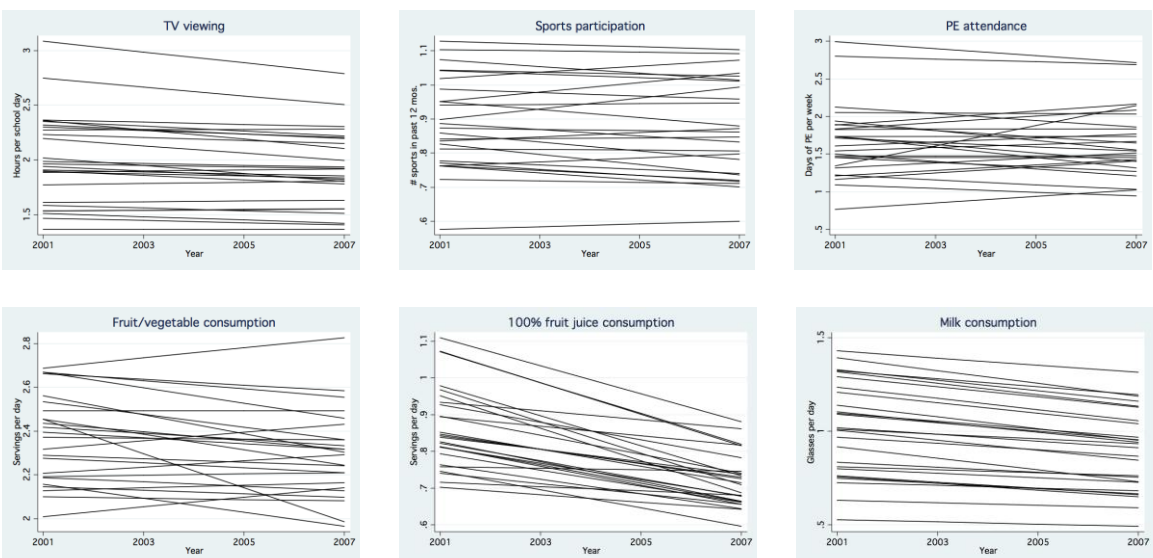
* Estimated 2001 mean, based on linear mixed model

Table 7. Cross-sectional association between weight-related behaviors and BMI percentile in the United States, by gender, Youth Risk Behavior Survey, 2001-2007

	Girls		Boys	
Behavior*	**ß**	**SE**	**ß**	**SE**
TV viewing	0.81	0.09	0.69	0.15
Sports participation	-3.12	0.41	1.46	0.36
PE attendance	-0.57	0.52	0.85	0.35
Fruit and vegetables	1.00	0.50	0.91	0.73
Milk	-0.30	0.90	2.75	0.63
100% fruit juice	-0.41	0.14	0.17	0.22

* Modeled as follows: TV viewing and 100% fruit juice (continuous), sports participation (binary, ≥1 per 12 months), PE attendance (binary, ≥1 day per week), fruits/vegetable consumption (binary, ≥5 per day), and milk consumption (binary, ≥4 glasses per day).

Figure 6. State-specific trends in weight-related behaviors* among adolescent girls in the United States, state Youth Risk Behavior Survey, 2001-2007



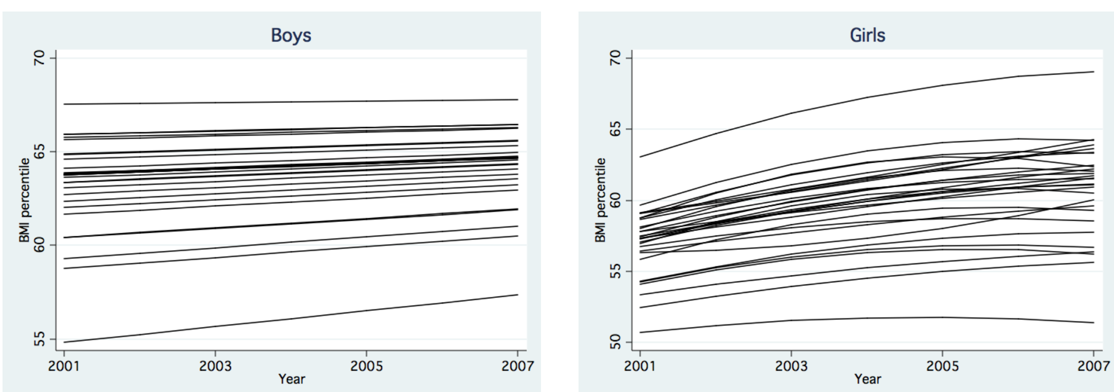
* All variables coded as continuous outcomes

Table 8. Proportion of variance of weight-related behaviors* and BMI percentile attributable to state differences overall (ICC_0) and state differences in time trends (ICC_T), and correlation between states' 2001 mean and time trend ($r_{\beta 0, \beta T}$)

		ICC_0	ICC_T	$r_{\beta 0, \beta T}$
TV viewing				
	Girls	0.07	0.0001	-0.63
	Boys	0.05	0.0004	-0.68
Sports participation				
	Girls	0.02	0.0001	-0.11
	Boys	0.01	0.0002	-0.49
PE attendance				
	Girls	0.05	0.0006	-0.40
	Boys	0.02	0.0006	-0.02
Fruits and vegetables				
	Girls	0.01	0.0002	-0.42
	Boys	0.01	0.0003	-0.63
100% fruit juice				
	Girls	0.01	0.0002	-0.74
	Boys	0.02	0.0003	-0.75
Milk				
	Girls	0.05	0.0001	-0.68
	Boys	0.05	0.0002	-0.72

* All variables coded as continuous outcomes

Figure 7. State-specific trends in BMI percentile among adolescent girls and boys, state Youth Risk Behavior Survey, 2001-2007



$ICC_0 = 0.01$
$ICC_T = 0.000008$ $r_{\beta 0, T} = -0.95$

$ICC_0 = 0.01$
ICC_T (linear) $= 0.0006$
ICC_T (quad) $= 0.00001$
$r_{\beta 0, \beta T}$ (linear) $= 0.21$
$r_{\beta 0, \beta T}$ (quad) $= -0.01$

Table 9. Mean change per year (standard error) in behavioral, demographic, and contextual variables among states in which mean BMI percentile among adolescents increased between survey years, $\Delta X_{BMI\,(\uparrow)}$, and states in which BMI percentile decreased between survey years, $\Delta X_{BMI\,(\downarrow)}$, by gender, Youth Risk Behavior Survey, 2001-2007.

	Girls		Boys	
	$\Delta X_{BMI\,(\uparrow)}$	$\Delta X_{BMI\,(\downarrow)}$	$\Delta X_{BMI\,(\uparrow)}$	$\Delta X_{BMI\,(\downarrow)}$
Behavioral variables*				
TV viewing	-0.01 (0.02)	-0.08 (0.02)	-0.04 (0.02)	-0.12 (0.03)
Sports participation (%)	-0.05 (0.56)	0.04 (0.81)	0.34 (0.55)	-0.46 (0.63)
PE attendance (%)	-0.50 (0.82)	-1.68 (1.25)	-0.69 (1.08)	0.62 (0.99)
Fruit/vegetables (%)	-0.11 (0.33)	0.09 (0.55)	-0.24 (0.37)	-0.59 (0.35)
Milk (%)	-0.54 (0.20)	-0.28 (0.18)	-1.30 (0.35)	-1.48 (0.37)
100% fruit juice	-0.06 (0.01)	-0.01 (0.02)	-0.05 (0.01)	-0.04 (0.02)
Demographic variables				
Age (years)	-0.02 (0.02)	0.03 (0.01)	-0.03 (0.01)	0.01 (0.02)
Race/ethnicity (%)				
Non-Hispanic White	-1.68 (0.32)	-0.67 (0.49)	-1.37 (0.40)	-1.48 (0.42)
Non-Hispanic Black	0.51 (0.23)	-0.23 (0.41)	0.19 (0.23)	0.55 (0.28)
Hispanic	0.91 (0.21)	0.54 (0.48)	0.92 (0.27)	0.64 (0.30)
Non-Hispanic Other	0.25 (0.19)	0.37 (0.47)	0.26 (0.31)	0.30 (0.22)
Contextual variables				
Poverty (%)	0.02 (0.09)	-0.18 (0.16)	0.00 (0.10)	-0.01 (0.14)
Income inequality†	0.59 (0.13)	0.46 (0.12)	0.50 (0.13)	0.64 (0.14)
Violent crime rate‡	-10.69 (6.85)	-1.74 (5.15)	-8.14 (5.11)	-8.27 (10.78)
Cigarette tax (cents)	7.90 (1.88)	15.04 (4.56)	8.89 (2.25)	11.5 (3.34)

* Changes in TV viewing and 100% fruit juice represent change in mean (hours per school day and servings per day, respectively); others represent change in prevalence on 0-100 scale (sports: ≥1 in past 12 months, PE attendance: ≥1 day per week during school year, fruits/vegetable consumption: ≥5 servings per day; milk consumption: ≥4 glasses per day).

† Measured by Gini coefficient, on a 0-100 scale

‡ Per 100,000

State policies targeting junk food in schools:

racial/ethnic differences in the effect of policy change on soda consumption

ABSTRACT

Introduction: School policies and practices regarding junk food have been associated with adolescent soda consumption. Many states have passed policies to restrict junk food in schools, but policy research has been limited to cross-sectional or single-state analyses. Our objective was to estimate the association between state policy changes over time and adolescent soda consumption in a multi-state sample, overall and by race/ethnicity.

Methods: As part of the 2000 and 2006 School Health Policies and Programs Study, states reported if they required or recommended schools to prohibit junk food in five settings (vending machines, snack bars, concession stands, parties, and breakfast/lunch periods.) Adolescents, grades 9-12, reported soda consumption, race, ethnicity, height, and weight as part of the 2007 state Youth Risk Behavior Surveillance System (YRBSS). Linear mixed models estimated the association between 2000-2006 state policy changes and 2007 student soda consumption and BMI percentile, and tested for racial/ethnic differences in the association, while adjusting for state correlates of legislative activity.

Results: Only policy changes targeting concession stands and parties were associated with soda consumption overall. Students in states that restricted junk food in concession stands consumed 0.09 fewer servings/day compared to students in states that did not (95% confidence interval: -0.17, -0.01). Soda consumption was 0.07 servings/day lower in state

that restricted junk food in parties (95% CI: -0.13, 0.00). In all settings, policy changes were associated with lower soda consumption primarily among non-Hispanic Blacks (up to 0.19 fewer servings/day). Policy changes were not associated with BMI percentile in any racial/ethnic group.

Discussion: State policies targeting junk food in schools may reduce racial disparities in soda consumption, but are not sufficient to reduce adolescent adiposity.

INTRODUCTION

The prevalence of obesity among adolescents in the United States has more than tripled in recent decades, increasing from 5% in 1976-80 to 18% in 2003-06.[10] This has created a large public health burden due to the association between obesity and type 2 diabetes, hypertension, dyslipidemia, sleep apnea, negative body image, low self-esteem, and depressive symptoms among adolescents.[19] During the same period in which obesity prevalence escalated, sources of energy intake among adolescents shifted toward greater consumption of soda and other sugar-sweetened beverages.[35-37] The proportion of energy intake from soft drinks increased among 2-18 year-olds from 3.0% in 1977-78 to 5.5% in 1994-96.[36] Furthermore, two systematic reviews reported that soft drinks have been associated with energy intake and weight gain in several cross-sectional and prospective cohort studies.[38, 39]

The 2000 School Health Policies and Programs Study (SHPPS) found that 98% of high schools in the U.S. offered a vending machine, school store, canteen, or snack bar in which foods and beverages were available for students to purchase, and 92% of high schools sold soda in at least one of these venues.[42] The widespread presence of soda and other foods and beverages of high caloric density has been recognized, and there has been a growing movement to remove them from schools.[7, 62, 81, 148] Between 2003 and 2005, states in the United States collectively introduced 213 bills and 25 resolutions targeting nutrition standards and vending machines in schools, and passed 13% and 36% of them, respectively.[9] These bills and resolutions included restricting access to vending machines and regulating the marketing of food and beverages with high caloric density and low nutrient density.

Although state and school policies have been enacted nationwide, little research has been done to evaluate the effect of policies targeting soda consumption. A recent study by Johnson et al. found that Washington State schools with stronger policies restricting sugar-sweetened beverages had lower student exposure to sugar-sweetened beverages, and that exposure was positively associated with sugar-sweetened beverage consumption, but their analysis was cross-sectional and at the school level.[149] In a cross-sectional study of a nationally representative sample of schools, sugar-sweetened beverage consumption was lower among students in high schools that limited the sale of competitive foods and had no store or snack bar selling foods or beverage.[150] In 2004, Texas implemented a statewide policy restricting portion sizes and availability of high-fat foods and sweetened beverages in all school food sources.[151] Compared to the years prior to policy implementation, students reported greater consumption of several nutrients and less consumption of snack chips and sweetened beverages at lunch.[96] The authors of the study did not compare Texas to other states, and it is unknown whether the changes they reported were attributable to the policy change or simply reflected a national or regional trend. To our knowledge, no study has compared food or beverage intake, or adiposity, between states that changed their policies and those that did not.

Some authors have suggested that schools are not a major source of sugar-sweetened beverage calories (<5%)[37] and students can easily compensate for policy changes by relying on other sources.[13, 15] Racial/ethnic minorities, in particular face disadvantages in the food built environment (i.e., human-made resources that influence diet) surrounding schools and in the community.[14, 15] Such disadvantages may explain why per capita consumption of sugar-sweetened beverages among 12-19 year-olds changed little among Whites between

1988-94 and 1999-2004, but increased from 268 to 297 kilocalories (kcal)/day among Blacks and from 248 to 305 kcal/day among Mexican-Americans.[37] The source of this disparity is unknown, however, as existing policy research has generally focused on ethnic majority populations.[17]

Our object was thus to estimate: 1) the effect of state policy changes targeting junk food in schools on soda consumption among adolescents overall, and 2) the difference in this effect across racial/ethnic groups. We hypothesized that soda consumption would be lower among adolescents in states that changed their school policies to restrict access to junk food, relative to adolescents in states that did not, and that this effect would be seen across all racial/ethnic groups. This study will help determine if school-based policies can offset disadvantages that racial/ethnic minorities face outside of school, and potentially reduce disparities in soda consumption.

METHODS

Policy data

Data on state policies regarding junk food in schools were obtained from the 2000 and 2006 SHPPS, a national survey that collected data on school health policies and practices at the state, district, school, and classroom levels.[124] The survey collects data on policies in eight component areas, including food services, and has been conducted every 6 years since 1994. All states and the District of Columbia participated in SHPPS in both 2000 and 2006.

State data were collected through computer-assisted telephone interviews or self-administered mailed questionnaires. Data were provided by personnel who were identified by the state education agency or department of health as being most knowledgeable about policies regarding food services. Following the 2000 SHPPS, Brener et al. studied the reliability and validity of data through interviews with respondents.[125] The authors generally did not report results for specific component areas, but interviews indicated that the survey produced valid data overall.

In both 2000 and 2006, respondents were asked if the state required or recommended that schools be prohibited from offering junk foods in 6 different settings:

- Breakfast and lunch periods
- Student parties
- After-school or extended day programs
- Concession stands
- Vending machines
- School stores, canteens, or snack bars

"Junk food" was defined in the 2000 survey as "foods that provide calories primarily through fats or added sugars and have minimal amounts of vitamins and minerals." The definition was slightly adapted in the 2006 survey to read, "foods or beverages that have low nutrient density, that is they provide calories primarily through fats or added sugars and have minimal amounts of vitamins and minerals." Participants could answer "require," "recommend," or "neither" for each of the 6 settings.

We combined policy data across settings to create a comprehensive policy score. 'Neither' was coded as 1, 'recommend' as 2, 'require' as 3, and the six settings were summed to calculate a score for both 2000 and 2006.

Student data

Student data were obtained from the 2007 state Youth Risk Behavior Survey (YRBS). YRBS is a biennial survey of 9th-12th grade students, administered on the national, state, and local levels. Students were sampled using a two-stage cluster sampling design, and data were weighted according to school and student response rates to produce estimates that are representative of the state jurisdiction.[109] Data were weighted only in states that provided appropriate documentation and had an overall response rate ≥ 60%. States were excluded if they did not meet these criteria (n = 5), did not participate in the 2007 YRBS (n = 6), did not measure soda consumption in 2007 (n = 1), did not provide all relevant policy data in the 2000 and 2006 SHPPS (n = 2), chose to not provide individual student data (n = 1), or determined that their data were not representative (n = 2). A total of 90,730 students from 34 states (AR, AZ, DC, DE, FL, GA, HI, ID, IL, IN, IO, KS, KY, ME, MA, MS, MO, MI, NV, NH, NM, NY, NC, ND, OH, RI, SC, TN, TX, UT, VT, WV, WI, WY) were included in this study.

Our outcomes of interest were servings of soda per day and body mass index (BMI) percentile. Using a written questionnaire administered in class, students were asked, "During the past 7 days, how many times did you drink a can, bottle, or glass of soda or pop, such as Coke, Pepsi, or Sprite?" Students also reported their height and weight, which was used to calculate BMI percentile. BMI percentile accounts for developmental differences between boys and girls of different ages by measuring each student's BMI relative to a reference population composed of children of the same age and sex in the U.S. from 1963-1994.[27] Brener et al. studied the validity of self-reported height and weight data and found that students overreported their height by an average of 2.7 inches and underreported their weight by 3.5 pounds, but the correlations with measured height and weight were 0.90 and 0.93, respectively.[114]

Students also reported their sex, race (American Indian or Alaska Native, Asian, Black or African-American, Native Hawaiian or Other Pacific Islander, White), and ethnicity (Hispanic/Latino or non-Hispanic) on the questionnaire. We combined categories of race and ethnicity to create a 4-category measure of race/ethnicity: non-Hispanic White, non-Hispanic Black, Hispanic, and non-Hispanic Other.

State covariates

State median income,[76] political party of the state legislature,[76, 77] and obesity prevalence among adults[76] and youth[78] have been associated with legislative activity targeting obesity. These variables can potentially confound the effect of soda policy change through their association with other types of policies (e.g., physical education requirements). We used a directed acyclic graph[143, 144] to identify income, political party, and adult obesity prevalence as variables to control for in our analysis, using data from the year 2000 to ensure that the variables were measured prior to policy change. Income data were obtained from the U.S. Census,[129] the prevalence of obesity among adults was obtained from the state Behavioral Risk Factor Surveillance System (BRFSS),[131] and state legislature political party following the 2000 election was obtained from the National Conference of State Legislatures.[132]

Statistical analysis

All analyses were based on the general linear mixed model, using an identity link and a random intercept to account for state clustering. Our primary analysis estimated the effect of policy changes that took place between 2000 and 2006 on servings of soda per day in 2007. Unless otherwise noted, models were restricted to states that reported 'neither' recommend nor require for the policy of interest in 2000. Policies in 2006 were used as the independent variable, and 'require' or 'recommend' were used as the index category (compared to 'neither'); the coefficients for 2006 policy thereby represented the effect of policy changes that took place between 2000 and 2006. Changes in policies targeting different settings (e.g., vending machines, snack bars) were analyzed in distinct models. All models adjusted for student sex, race/ethnicity, state log median income, state adult obesity prevalence, and whether the state legislature was controlled by the Democratic party.

After estimating the overall association between policy change and soda consumption for each policy measure, we tested for differences in the association across racial/ethnic groups. We repeated the model after adding an interaction term between 2006 policy and each racial/ethnic group except non-Hispanic Whites; we calculated the association between policy change and soda consumption in each group by adding the appropriate coefficients. A likelihood ratio test was used to determine if the overall interaction between race/ethnicity and policy was statistically significant ($\alpha = 0.05$, df = 3).

After modeling the associations between policy measures and soda consumption, we repeated each model with BMI percentile as the outcome. Throughout the analysis, we did not adjust for multiple testing. All analyses were conducted with Mplus Version 5.21 to incorporate the sampling weights in the YRBS.[139]

RESULTS

Weighted descriptive statistics are provided in Table 10. Overall, the sample was 62% non-Hispanic White, 18% non-Hispanic Black, 15% Hispanic, and 5% non-Hispanic Other. The racial/ethnic groups had similar distributions of age and gender. The shape of the distribution of soda consumption was positively skewed in all racial/ethnic groups, with a median of 0.7 servings per day and a mean of 1.0. The mean number of servings of soda per day was highest among non-Hispanic Blacks, who had an unusually high percentage of participants reporting 4 or more servings per day (10%). The prevalence of reporting one or more servings per day was greatest among non-Hispanic Whites. Both the mean daily servings and the prevalence of one or more servings per day were noticeably lower in the non-Hispanic Other group. The prevalence of obesity ranged from 11.4% among non-Hispanic Whites to 16.3% among Hispanics.

Figure 8 shows how the distribution of state policies shifted over time, with more states requiring or recommending that schools prohibit junk foods in 2006 compared to 2000. In 2000, at least 28 out of the 34 participating states reported that they neither recommended nor required that schools be prohibited from offering junk food in vending machines, snack bars, concession stands, and parties. By 2006, however, 11 states required schools to prohibit junk foods in vending machines, while 10 other states recommended it, and the same was true for policies regarding junk food in snack bars. Few states required schools to prohibit junk foods in concession stands or parties in 2006, but 10 states recommended it for concession stands and 9 recommended it for parties. A relatively large number of states (n = 15) required or recommended that junk foods be prohibited during breakfast and lunch periods in 2000, but the number that required it doubled (from 7 to 14) from 2000 to 2006.

These distributions were used to choose comparison groups when modeling the association between policy change and soda consumption. For snack bars, vending machines, concession stands, and parties, states reporting ‘neither’ were the referent, and states that reported ‘require’ or ‘recommend’ were combined into one index category. Among these, only policy changes targeting concession stands and parties were associated with self-reported soda consumption (Table 11). The mean number of servings per day was 0.09 lower among adolescents in states that required or recommended that junk food not be allowed in concession stands, relative to adolescents in states that did not (95% CI: -0.17, -0.01). The effect size for parties was slightly weaker (β =0.07; 95% CI: -0.13, 0.00). For snack bars and vending machines, we examined another model using only states that reported ‘require’ as an index category (those that reported ‘recommend’ were excluded), and found no association. For breakfast and lunch periods, we found no association when comparing states that strengthened their policy (from ‘neither’ to ‘recommend’ or ‘require’, or from ‘recommend’ to ‘require’) to those that reported ‘neither’ in both years. We also found no association between change in the comprehensive policy score and soda consumption. Policies regarding school programs were not modeled because the distribution changed little between 2000 and 2006

Although most associations were null in the sample overall, they differed by race/ethnicity and particularly between non-Hispanic Whites and non-Hispanic Blacks (Table 12). Across all settings, there was no association among non-Hispanic Whites, but a negative association, as hypothesized, among non-Hispanic Blacks. The coefficients for concession stands among non-Hispanic Blacks (difference = -0.19) suggests that adolescents whose state changed their school policies consumed approximately 1.33 fewer servings per week (= 7 days*0.19) compared to those who resided in states that did not change their policies. The associations in other settings were slightly weaker. Across most settings, the difference between non-Hispanic Whites and non-Hispanic Blacks in the association between policy change and soda consumption was of a similar magnitude as the difference in mean soda consumption between the two groups (Table 10). Among Hispanics, the estimated associations were slightly weaker and less precise than non-Hispanic Blacks. There was no difference in the association between policy change and soda consumption between non-Hispanic Whites and non-Hispanic Other.

Table 13 displays the association between policy change and 2007 BMI percentile, by race/ethnicity. Although the overall interaction between race/ethnicity and policy was statistically significant for each setting except school parties, this was largely driven by unusually large associations among non-Hispanic Other adolescents. In each of the other racial/ethnic groups, BMI percentile was similar among adolescents in states that changed their policies, relative to those in states that did not. We explored the effect among non-Hispanic Other adolescents by examining the distribution of policies and BMI percentile within individual racial/ethnic categories (American Indian/Alaka Native, Asian, Native Hawiian/Pacific Islander, and Multiple/Non-Hispanic) and found that they differed particularly between American Indian/Alaska Natives and Asians. For policies targeting snack bars, for example, 68% of American Indian/Alaska Natives lived in states that reported ‘require’ or ‘recommend’, compared to only 50% of Asians. The mean BMI percentile among American Indian/Alaska Natives was almost 10 units higher compared to Asians (64.3 and 54.7, respectively).

DISCUSSION

To our knowledge, this was the first study to estimate the association between state policy changes targeting junk food in schools and adolescent soda consumption or adiposity in a national sample. Interestingly, we found that the association was generally restricted to non-Hispanic Blacks, among whom consumption of sugar-sweetened beverages has increased in recent years.[37] States that did not recommend or require that junk foods be prohibited in schools in 2000, but did in 2006, had lower levels of soda consumption among non-Hispanic Black adolescents compared to states that did not change their policy, but similar consumption among non-Hispanic White adolescents. The difference in effect size between non-Hispanic Blacks and non-Hispanic Whites was similar to the difference in mean servings per day overall. This suggests that state policies targeting junk food in schools may be a means to reduce disparities in soda consumption between these groups.

These results add to studies by Johnson et al.[149] and Briefel et al.;[150] both found that school policies and practices were associated with sugar-sweetened beverage exposure or consumption among students. Cullen et al. also reported a decrease in sweetened beverage consumption following state policy change.[96] This study adds to the evidence base by using multiple years of policy data in a national sample, restricting the analysis to states that did not recommend or require junk foods to be prohibited in 2000, and controlling for state variables that may have motivated policy change. This prospective design provides additional evidence that policy changes may lead to lower soda consumption, though causality cannot be inferred due to the observational design.

Our study also builds on existing research by highlighting concession stands and parties as areas where states and schools may influence adolescent soda consumption. Both settings are sources of junk food that have generally been ignored in previous research, yet they had the strongest associations with soda consumption in every racial/ethnic group in our study. In their prospective study of the effect of advertising on adolescent alcohol consumption, Ellickson et al. similarly found that concession stands were the only setting in which advertising was associated with 9th-grade consumption among both 7th-grade drinkers and non-drinkers.[152] Concession stands may include events that lie within a school's jurisdiction even though they take place outside of the school day (e.g., football games). This raises questions as to whether adolescent soda consumption primarily takes place outside of school hours, while identifying a means by which schools may still influence consumption. Additional research is needed to explore which sources students primarily rely upon for soda and other energy-dense foods and beverages.

Despite the association between policy change and soda consumption among non-Hispanic Blacks, there was no association between policy change and BMI percentile. Cawley et al. reported similar results when studying the effect of state policies regarding physical education (PE) requirements.[98] State PE requirement policies were associated with minutes of activity during PE, but there was no association between minutes of activity during PE and obesity among boys or girls. A recent study by Powell et al. also found that state soda taxes were not associated with adolescent BMI,[153] which suggests that complete absence of soda may have a larger impact on soda consumption than modest price increases. The failure of policies to affect BMI or obesity, even if they change individual behaviors, may be an indication that the effect on behaviors is too small. The largest effect size in any racial/ethnic group in our study was only 0.19 servings per day. The serving sizes were not standardized, but if a serving represented a 20-oz. bottle, 0.19 servings would represent <50 kilocalories (kcal). Hill et al. reported that the energy gap that accounts for weight gain in the U.S. population is twice as high (100 kcal/day),[154] and other studies have reported that the energy gap is larger.[155, 156] Therefore, even an effect size of 0.19 servings may be insufficient to change BMI percentile. There also may have been insufficient time to affect BMI percentile, and longer follow-up may be needed to detect a change, or the study may not have had sufficient power to detect an effect.

Furthermore, students may be compensating for changes in soda consumption by consuming different kinds of junk foods or sugar-sweetened beverages (e.g., sports drinks). Cullen et al. reported that, after policies restricted student access to certain junk foods from snack bars and vending machines, consumption of the targeted foods often decreased, but consumption of other junk foods increased and students obtained junk foods from different sources (e.g., home).[90, 96] Students' ability to compensate has led some researchers to question the idea of using school policies as an intervention to reduce obesity.[13, 15]

Compensation among students led Cullen et al. to conclude that all food environments must be targeted if policies are to have an impact. Hispanics, in particular, face disadvantages in the food built environment outside of school,[14, 15] and may be able to compensate more easily than other racial/ethnic groups as a result. To address these challenges, several researchers and policymakers have called for comprehensive policy change at the federal, state, and local levels.[5-8, 62] Policies targeting a range of different diet and physical activity behaviors across a range of sectors may be more effective in overcoming compensation and reducing BMI and obesity.[89] Future research should explore the cumulative effect of comprehensive policy changes, and continue to explore if the effect of comprehensive change can reduce disparities in both soda consumption and obesity.

Limitations

Several limitations should be considered when interpreting these findings. Soda consumption, height, and weight were self-reported, and adolescents commonly over-report height,[114] under-report weight,[114] and under-report dietary intake.[157] The accuracy of self-reported height and weight may also vary by race/ethnicity.[158] Consumption was measured in terms of servings, not a standard serving size, which precludes us from concluding that policies were associated with lower energy intake from soda. We could not examine whether policy changes caused within-student change in soda consumption because consumption was not measured until 2007, nor could we measure exactly when policy changes took place because policy data were collected in 2000 and 2006 only. If changes occurred in 2006, for example, there may not have been sufficient time for them to affect BMI percentile. These constraints also limit our ability to adjust for variables that may have motivated policy changes. State policies may also have varied with respect to language (e.g., different states may restrict different types of foods and beverages.) Finally, the analysis was restricted to 34 states, which may have limited our power to detect effects of policies on BMI percentile or on soda consumption across different racial/ethnic groups.

Conclusions

In conclusion, this study provides evidence that changes in state policies restricting junk food in schools can reduce soda consumption among adolescents, particularly non-Hispanic Blacks. The effect of individual policies may be too weak to reduce adolescent obesity, however. These findings support the need for comprehensive policy change, in and outside of schools, and suggest that additional research is needed to evaluate the impact of comprehensive change on obesity.

TABLES & FIGURES

Table 10. Descriptive statistics of the 2007 YRBS sample among states that provided policy data in 2000 and 2006, overall and by race/ethnicity

	Overall	**White***	**Black***	**Hispanic**	**Other***
Sample size	90730	51285	13051	15444	8450
Gender (%)					
Male	50.7	50.5	49.8	50.6	53.1
Female	49.3	49.5	50.2	49.4	46.9
Age (%)					
≤14	10.3	9.6	10.1	11.8	13.8
15	26.1	26.1	25.4	26.4	27.4
16	26.1	25.9	26.5	26.2	26.8
17	23.7	24.1	24.3	22.8	20.5
≥18	13.9	14.4	13.7	12.8	11.4
Soda consumption					
Servings per day (mean)	0.978	0.965	1.06	0.979	0.876
>1 serving per day (%)	32.1	33.0	31.6	31.6	27.0
Anthropometric variables					
BMI percentile† (mean)	62.8	60.7	68.6	66.5	60.2
Obesity (%)	12.9	11.4	15.7	16.3	13.4

* Non-Hispanic
† BMI relative to a reference population composed of children of the same age and sex in the U.S. from 1963-1994

Figure 8. Distribution of state policies regarding junk food in schools in 2000 and 2006 School Health Policies and Programs Study (SHPPS) among states in the study sample (n=34)

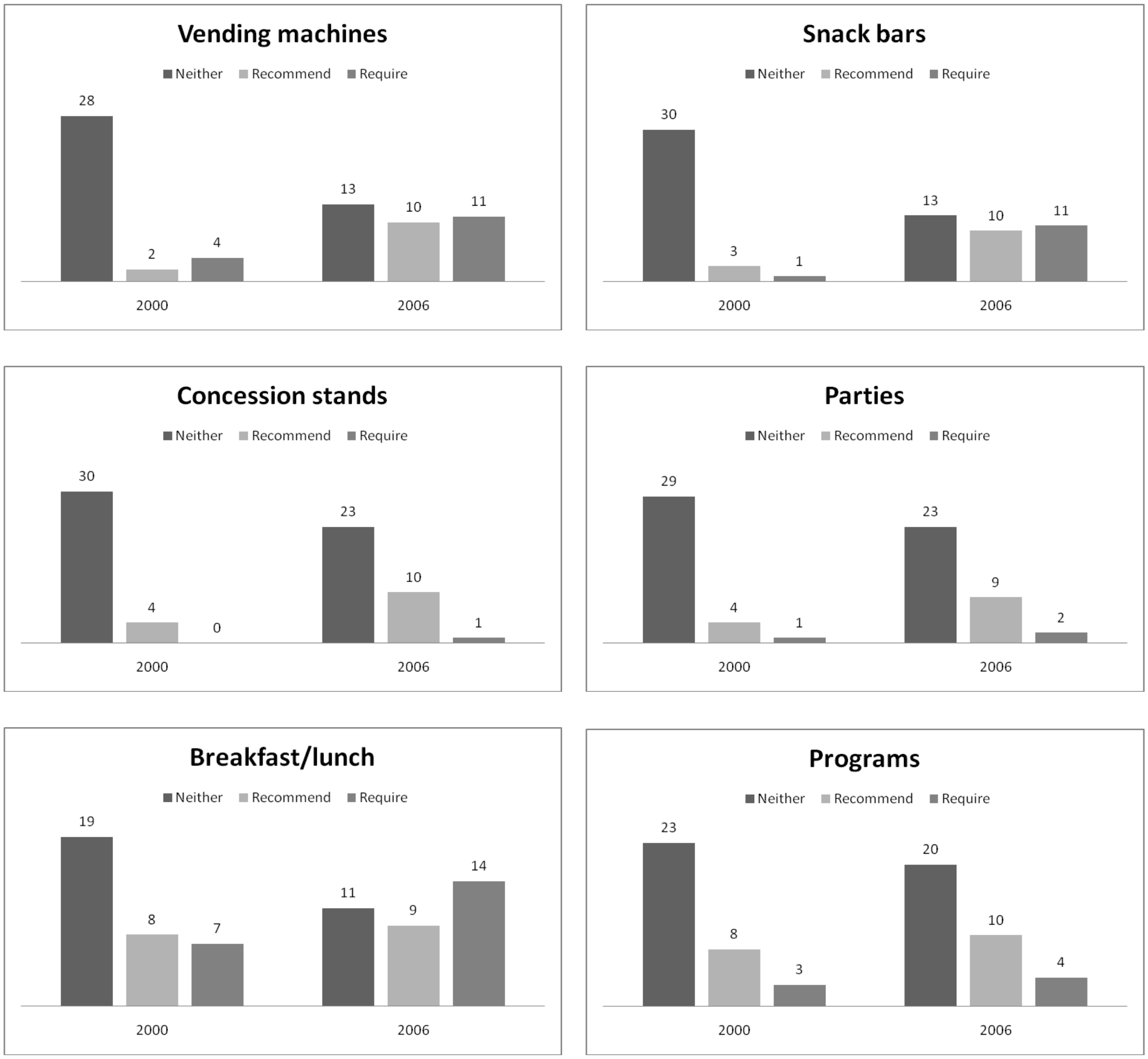


Table 11. Adjusted* mean daily servings of soda in states with policy changes targeting junk food in schools ('Yes') and those without, among 9th-12th grade students in 2007

			Difference†	
Setting	**Yes**	**No**	**Mean**	**95% CI‡**
Vending machines				
Recommend or require	1.00	0.95	0.04	-0.05, 1.13
Require	0.98	0.96	0.02	-0.07, 0.10
Snack bars				
Recommend or require	0.99	0.96	0.03	-0.06, 0.12
Require	0.98	0.97	0.01	-0.08, 0.11
Concession stands§	0.91	1.00	-0.09	-0.17, -0.02
Parties§	0.92	0.99	-0.07	-0.13, 0.00
Breakfast/lunch#	1.01	0.95	0.06	-0.06, 0.19
Total score	-	-	0.00	-0.01, 0.01

* Adjusted for student sex and race/ethnicity, and state-level log per capita income, obesity prevalence, and political party of state legislature

† The difference between daily servings of soda among students in states that required/recommended schools to prohibit junk food and states that did not (referent), after adjustment for the covariates included in the model.

‡ CI: Confidence Interval

§ 'Recommend or require' compared to 'neither' (referent)

States that strengthened their policy (from 'neither' to 'recommend' or 'require,' or from 'recommend' to 'require') compared to states that reported 'neither' in both years (referent)

Table 12. Racial/ethnic-specific association between state policy changes targeting junk food in schools and daily soda consumption among 9th-12th grade students in 2007*

	White[†]		**Black**[†]		**Hispanic**		**Other**[†]	
Setting	**Difference**[‡]	**SE**[§]	**Difference**[‡]	**SE**[§]	**Difference**[‡]	**SE**[§]	**Difference**[‡]	**SE**[§]
Vending machines								
Recommend or require	0.08	0.05	-0.07[§]	0.06	0.00	0.09	0.11	0.07
Require	0.08	0.05	-0.12[§]	0.06	-0.06	0.09	0.04	0.07
Snack bars								
Recommend or require	0.06	0.05	-0.07[§]	0.06	-0.02	0.10	0.13	0.07
Require	0.06	0.05	-0.12[§]	0.06	-0.08	0.10	0.09	0.07
Concession stands[#]	-0.07	0.05	-0.19[§]	0.06	-0.11	0.09	-0.02	0.08
Parties[#]	-0.04	0.04	-0.14[§]	0.06	-0.12	0.08	-0.03	0.08
Breakfast/lunch**	0.09	0.07	-0.05[§]	0.08	0.00	0.11	0.15	0.08
Total score	0.01	0.01	-0.02[§]	0.01	-0.01	0.01	0.00	0.01

* p <0.001 for likelihood ratio test of interaction between race/ethnicity and policy (degrees of freedom = 3)
[†] Non-Hispanic
[‡] The difference between daily servings of soda among students in states that required/recommended schools to prohibit junk food and states that did not (referent), adjusted for student sex and state-level log per capita income, obesity prevalence, and political party of state legislature
[§] SE: Standard error of difference
[#] 'Recommend or require' compared to 'neither' (referent)
** States the strengthened their policy (from 'neither' to 'recommend' or 'require,' or from 'recommend' to 'require') compared to states that reported 'neither' in both years (referent)

Table 13. Racial/ethnic-specific association between state policy changes targeting junk food in schools and BMI percentile among 9^{th}-12^{th} grade students in 2007

	White*		Black*		Hispanic		Other*		
Setting	**Difference**[†]	**SE**[‡]	**Difference**[†]	**SE**[‡]	**Difference**[†]	**SE**[‡]	**Difference**[†]	**SE**[‡]	**LR test**[§]
Vending machines									
Recommend or require	-0.71	1.34	0.31	1.64	0.78	2.06	2.94	3.57	p<0.001
Require	-1.09	1.61	-0.20	1.88	-0.34	2.47	4.09	4.22	p<0.001
Snack bars									
Recommend or require	-0.51	1.25	0.83	1.54	0.76	2.00	4.47	3.19	p<0.001
Require	-0.77	1.43	0.64	1.72	-0.29	2.28	5.48	3.61	p<0.001
Concession stands[#]	-0.88	1.00	-0.54	1.46	-1.91	1.67	1.69	3.32	p=0.02
Parties[#]	-0.63	0.92	0.08	1.32	-1.29	1.61	1.34	3.37	p=0.09
Breakfast/lunch**	-0.64	1.53	0.88	1.80	1.83	2.22	5.25	3.41	p<0.001
Total score	-0.19	0.13	-0.02	0.20	-0.11	0.22	0.21	0.42	p=0.007

* Non-Hispanic
[†] The difference between BMI percentile among students in states that required/recommended schools to prohibit junk food and states that did not (referent), adjusted for student sex and state-level log per capita income, obesity prevalence, and political party of state legislature
[‡] SE: Standard error of difference
[§] Likelihood ratio test for interaction between race/ethnicity and policy (degrees of freedom = 3)
[#] 'Recommend or require' compared to 'neither' (referent)
** States the strengthened their policy (from 'neither' to 'recommend' or 'require,' or from 'recommend' to 'require') compared to states that reported 'neither' in both years (referent)

DISCUSSION

Summary of findings

We used several years of surveillance data, advanced statistical techniques, and a variety of student- and state-level analyses to estimate state disparities in time trends of adolescent adiposity and weight-related behaviors, and determine if policy changes predicted state differences in soda consumption and adiposity. States exhibited differences in virtually all behaviors that we analyzed regardless of whether the states were being compared with respect to policy changes or simply time. Yet, with the possible exception of TV viewing, behavioral differences across states were never accompanied with differences in adiposity. Simply put, self-reported behaviors were not the reason why adolescent adiposity differed by state, nor were they the reason that adolescent BMI percentile continued to increase throughout the United States from 2001 to 2007 in spite of state legislation to reduce obesity.

This does not discount the potential positive impact of state policies. We found an association between policy change targeting junk food in schools on soda consumption among non-Hispanic Blacks, indicating that such policies may reduce racial/ethnic disparities in soda consumption. This addresses a hole in the field of obesity policy research, which has not focused on racial/ethnic minorities,[17] while countering the hypothesis that fast-food restaurants and other establishments that provide energy-dense foods and beverages may negate the effect of school policies among minorities.[13, 15] We also identified concession stands and school parties as settings for policy intervention that have not been explored to this point.

Strengths and limitations

Both aims benefited from the volume of state-representative data collected across multiple states and years. Aim 1 included more than 272,000 students from 29 states sampled across a seven-year span, and Aim 2 included more than 90,000 students in 34 states and state policy data collected six years apart. Analyses in both aims utilized statistical techniques and software to account for both state clustering and the complex sample design of YRBSS. We analyzed a wide range of diet and physical activity behaviors believed to be associated with youth obesity. Aim 2 also adds to existing cross-sectional studies of obesity policies by analyzing the association between changes in state policies over time and both behavior and adiposity, while controlling for variables that may have motivated policy change.

A key limitation of this work is that all data were self-reported. Height and weight, in particular, have been shown to be mis-reported in such a way that they underestimate BMI.[114] The validity of the YRBS behavioral questions has not been studied, but given the challenges of measuring diet and activity by self-report,[34] measurement error with these behaviors is a strong possibility. The moderate reliability of physical activity and sedentary behavioral YRBS measures may have caused an underestimate of the association between these behaviors and BMI percentile in Aim 1, and the reliability of dietary YRBS measures is unknown. Another limitation is that all analyses remain cross-sectional despite using several years of data. Individual students were not followed over time, which limits the ability to make inferences regarding the causal effect of policy change or the shape, direction, and between-state variation of time trends. Individual students also did not provide data on socioeconomic status, which may have confounded several of the associations that were estimated. Finally, the analyses were limited to high school students, and not all states participated in the survey. Results are therefore not generalizable to elementary or middle schools, or non-participating states.

Aim 2 was also limited by the quality of policy data in SHPPS. There was little detail in the SHPPS questions, which may have obscured between-state variability in policies. For example, two states may have reported that they require schools to prohibit ‘junk food’ in vending machines, but one of the states specifically required that sweetened beverages be prohibited while the other only required that foods be prohibited. Furthermore, there is limited knowledge of the validity or reliability of SHPPS measures. The precise timing of the policy change was also unknown, limiting the ability to attribute causality even when an association was detected. This also limits the ability to determine if there was sufficient time for policy changes to have an impact. Removing junk food from vending machines is a major institutional change that can take time to implement, particularly if schools rely on vending machines as a source of revenue. Even if states officially changed their policy regarding vending machines by 2006, it is conceivable that the changes were not fully implemented in time for them to impact soda consumption or adiposity.

Public health implications

Aim 1

Across states and gender groups, there was a consistent pattern of convergence, as` populations that had a lower BMI percentile in 2001 appeared to be “catching up” over time. The positive side to this finding is that both geographic and gender disparities shrank over time; the negative side is that, if this trend were to continue, it is conceivable that adolescent obesity prevalence will continue to escalate as populations that have had a low prevalence in the past experience an increase. Additional surveillance is needed to ensure that the plateau that was found by Ogden et al. in NHANES[10] was not temporary.

The lack of association between most behaviors and BMI percentile, on the student or state level, raises question as to whether common school-based policies such as PE requirements are likely to have an impact. Though policies were not directly tested in Aim 1, data were analyzed from a variety of angles and consistently suggested that differences in most behaviors that were analyzed did not translate into differences in adiposity. The only behavior that was associated with BMI percentile (TV viewing) generally takes place outside of school and falls outside the jurisdiction of schools. The act of watching TV is difficult to regulate, but this does not mean that, if TV increases adiposity, the effect cannot be modified through policy. Such an effect may be mediated through several mechanisms, including increased exposure to marketing of energy-dense foods.[159] Food advertising represents 26% of TV product advertising that adolescents see, and 62% of it is for fast-food restaurants, sweets, and beverages.[160] To this point, regulatory efforts and marketing research have both generally focused on younger children (age 12 or less).[161] Therefore, from the perspectives of both researchers and policymakers, TV marketing represents an untapped area on which to focus efforts to reduce adolescent obesity.

Aim 2

The results of this work support both those who advocate policy interventions[5-8, 62] and those who believe the policies can easily be negated in an obesogenic environment.[13, 15] They add to a growing body of literature that suggests that school-based policies can have a positive impact on behaviors,[17, 88] while casting doubt on the ability of school policies to reduce adiposity unless they are part of a comprehensive intervention that targets different aspects of adolescents' food and physical activity built environment.[93, 94, 96] Isolated changes to students' environment may not affect students' energy gap because students have countless ways to adapt through different resources. In this sense, the results of Aim 2 reinforce those of Aim 1 by suggesting that schools cannot reduce adiposity without help from other sectors. The increase in youth obesity took place during a period when there were striking trends in environmental determinants controlled by many public and private sectors (e.g., food industries, urban planning, transportation systems).[42-48] With so many societal trends taking place, one cannot realistically expect individual policies targeting individual determinants in individual sectors to reduce obesity. These environmental trends largely fall outside the jurisdiction of schools, but are amenable to policy intervention through other sectors. Taxes, zoning regulations, building codes, transportation regulations, trans fat bans, and menu labeling are examples of policies that have been promoted or enacted in an effort to address these trends.[162-165] Comprehensive legislation that addresses both school and community environments may be more effective in reducing adiposity compared to individual school policies.

Future research

The obvious recommendation for future studies is to estimate the effect of different types of policies across sectors. Marketing regulations and other policy changes face political and legal challenges[166] that will be difficult to overcome without evidence of policy effectiveness, and currently there is insufficient evidence supporting most of them.[164] Two preliminary steps are needed prior to studying policy effectiveness, however: 1) improving comprehensive measures of policies across sectors, and 2) understanding determinants of policy adoption.

Comprehensive policy change requires comprehensive measures to evaluate it. Recent studies have proposed comprehensive school policy measures that encompass different aspects of the school environment,[78, 167, 168] but to this point these measures have not been used to evaluate the effect of policy change. Furthermore, no study has attempted to link school- and non-school-based policies (e.g., policies regarding land use around schools). Substantial groundwork must be done to develop research in this area, and it will require experts from many different areas beyond public health (economics, political science, and urban planning, just to name a few).[164, 169]

It is natural to assume that evidence of effectiveness will cause policy makers and the public to support policy interventions, but some studies have suggested that such evidence is of secondary importance. Hawkes reviewed movements to regulate food marketing to youth, for example, and concluded that movements were not driven by evidence that marketing regulations have an effect as much as by ethical concerns that children were being taken advantage of.[170] Gollust et al. conducted an experiment in which they presented fictional headlines about evidence of social determinants of diabetes to Republicans and Democrats, and the authors found that the evidence caused support for policy intervention to diverge across parties.[171] Several social, economic, and political variables have also been associated with proposal or enactment of obesity legislation.[76-78] Understanding the determinants of policy action is critical from both a research and policymaking perspective. Some determinants may bias the estimated effect of policy change, and thus must be controlled for, while being conscious of factors that influence policy support will enhance policymakers' ability to enact effective policies.

Research of obesity policies should also include a combination of efficacy and effectiveness trials. That is, some studies should assess the impact of policy changes under well-controlled conditions in which implementation is carefully executed, while other studies allow more "real world" conditions that are less controlled. The study of school-based policy changes in this dissertation focused more on the latter by not controlling for implementation; this was purposely done to study the effect that existing policy changes have had under actual circumstances, as opposed to perfectly-controlled circumstances. Studies that control implementation can also be informative, however, by demonstrating if policy changes have the potential to have an impact when implemented and, if so, what the causal mechanisms are. It is unknown whether any positive effects of school policy changes are due to changes in the school environment per se, changes in social norms related to food and physical activity, or some other factor. Understanding the causal mechanisms may improve the effectiveness of future policy interventions.

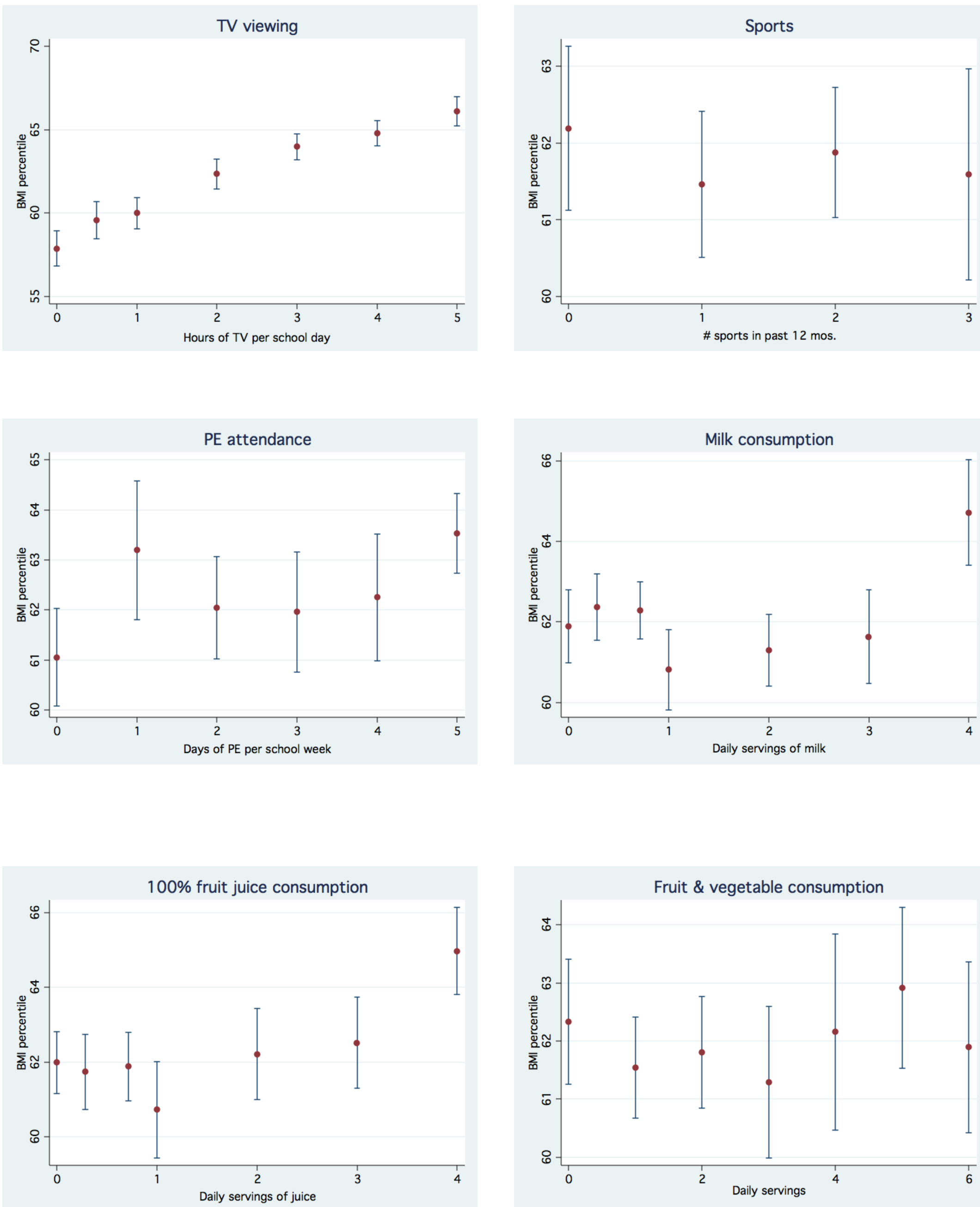
Conclusion

The work demonstrates the positive impact that school-based policy changes may have on adolescent diet. The scope of change that has taken place in schools nationwide in the past decade appears to have been a drop in the bucket, however, as adolescent adiposity did not cease to increase in the U.S., much less decline. Researchers and policymakers should continue to focus on schools while identifying other targets for policy intervention, particularly environmental determinants that have plagued minorities and low-SES groups. The policy changes that have already taken place are an indication that, after years of educating individuals to eat well and be active, many public health professionals and policymakers recognize that this approach alone will not reduce obesity. The greatest public health achievements of the 20th century were orchestrated through bold social, political, and economic change. The same will likely be necessary to mitigate one of the primary public health issues of this era.

APPENDICES

Appendix A: Dose-response analyses

Figure 9. Cross-sectional association between weight-related behaviors and BMI percentile in the United States, Youth Risk Behavior Survey, 2001-2007



Appendix B: Sensitivity analysis of case-control analysis

Table 14. Mean change per year (standard error) in behavioral, demographic, and contextual variables among states in which mean BMI percentile among adolescents increased between survey years by at least 0.5 units, $\Delta X_{BMI\,(\uparrow)}$, and states in which BMI percentile decreased between survey years by at least 0.5 units, $\Delta X_{BMI\,(\downarrow)}$, by gender, Youth Risk Behavior Survey, 2001-2007

	Girls		**Boys**	
	$\Delta X_{BMI\,(\uparrow)}$	$\Delta X_{BMI\,(\downarrow)}$	$\Delta X_{BMI\,(\uparrow)}$	$\Delta X_{BMI\,(\downarrow)}$
Behavioral variables*				
TV viewing	0.02 (0.02)	-0.12 (0.03)	-0.02 (0.03)	-0.13 (0.03)
Sports participation (%)	-0.09 (0.59)	-0.16 (1.05)	0.18 (0.64)	-0.88 (0.71)
PE attendance (%)	-0.41 (0.91)	-2.32 (1.25)	-0.58 (1.30)	0.48 (1.05)
Fruit/vegetables (%)	-0.03 (0.37)	0.12 (0.75)	-0.37 (0.41)	0.41 (0.42)
Milk (%)	-0.50 (0.21)	-0.33 (0.22)	-1.35 (0.38)	-1.51 (0.42)
100% fruit juice	-0.06 (0.01)	0.00 (0.02)	-0.05 (0.01)	-0.03 (0.02)
Demographic variables				
Age (years)	-0.02 (0.02)	0.06 (0.01)	-0.04 (0.02)	0.00 (0.02)
Race/ethnicity (%)				
Non-Hispanic White	-1.67 (0.36)	0.74 (0.64)	-0.89 (0.39)	-1.27 (0.53)
Non-Hispanic Black	0.70 (0.26)	-0.14 (0.59)	0.02 (0.26)	0.48 (0.32)
Hispanic	0.88 (0.23)	0.66 (0.53)	0.88 (0.32)	0.51 (0.35)
Non-Hispanic Other	0.09 (0.20)	0.21 (0.65)	-0.01 (0.32)	0.28 (0.27)
Contextual variables				
Poverty (%)	0.00 (0.10)	-0.12 (0.17)	0.01 (0.12)	-0.23 (0.17)
Income inequality†	0.58 (0.15)	0.48 (0.12)	0.53 (0.16)	0.69 (0.17)
Violent crime rate‡	-11.80 (7.95)	-1.85 (6.69)	-9.61 (6.13)	2.80 (5.61)
Cigarette tax (cents)	0.07 (0.02)	0.14 (0.05)	0.10 (0.03)	0.11 (0.04)

* Changes in TV viewing and 100% fruit juice represent change in mean (hours per school day and servings per day, respectively); others represent change in prevalence on 0-100 scale (sports: ≥1 in past 12 months, PE attendance: ≥1 day per week during school year, fruits/vegetable consumption: ≥5 servings per day; milk consumption: ≥4 glasses per day).

† Measured by Gini coefficient, on a 0-100 scale

‡ Per 100,000

Appendix C: Racial/ethnic differences in the association between policy change and soda consumption

Table 15. Difference between non-Hispanic Whites and other racial/ethnic groups in the association between policy change and soda consumption among 9th-12th grade students in 2007

	White†		**Black**†		**Hispanic**		**Other**†	
Setting	**Difference**‡	**SE**§	**Difference**‡	**SE**§	**Difference**‡	**SE**§	**Difference**‡	**SE**§
Vending machines								
Recommend or require	-	-	-0.14	0.04	-0.08	0.08	0.03	0.05
Require	-	-	-0.20	0.05	-0.14	0.08	-0.04	0.06
Snack bars								
Recommend or require	-	-	-0.13	0.03	-0.08	0.08	0.07	0.05
Require	-	-	-0.18	0.04	-0.14	0.08	0.03	0.05
Concession stands**	-	-	-0.12	0.04	-0.05	0.07	0.05	0.07
Parties**	-	-	-0.10	0.04	-0.08	0.08	0.01	0.07
Breakfast/lunch††	-	-	-0.14	0.04	-0.09	0.09	0.06	0.05
Total score	-	-	-0.03	0.01	-0.02	0.01	0.00	0.01

* Policy on whether state requires or recommends that schools be prohibited from offering junk food in different settings

† Likelihood ratio test for interaction between policy change and race/ethnicity (degrees of freedom = 3) was statistically significant ($p<0.001$) for each policy setting

‡ Non-Hispanic

§ The difference between daily servings of soda among students in states that required/recommended schools to prohibit junk food and states that did not (referent), adjusted for student sex and state-level log per capita income, obesity prevalence, and political party of state legislature

SE: Standard error of difference

** ‘Recommend or require’ compared to ‘neither’ (referent)

†† States the strengthened their policy (from ‘neither’ to ‘recommend’ or ‘require,’ or from ‘recommend’ to ‘require’) compared to states that reported ‘neither’ in both years (referent)

Appensix D: Racial/ethnic differences in the association between policy change and BMI percentile

Table 16. Difference between non-Hispanic Whites and other racial/ethnic groups in the association between policy change and BMI percentile among 9th-12th grade students in 2007

	White†		**Black†**		**Hispanic**		**Other†**	
Setting	**Difference‡**	**SE§**	**Difference‡**	**SE§**	**Difference‡**	**SE§**	**Difference‡**	**SE§**
Vending machines								
Recommend or require	-	-	1.02	1.07	1.49	1.63	3.65	3.34
Require	-	-	0.89	1.17	0.74	1.97	5.18	3.95
Snack bars								
Recommend or require	-	-	1.33	1.01	1.27	1.60	4.98	2.97
Require	-	-	1.41	1.11	0.48	1.85	6.25	3.36
Concession stands**	-	-	0.35	1.17	-1.02	1.41	2.57	3.20
Parties**	-	-	0.71	1.06	-0.67	1.40	1.96	3.28
Breakfast/lunch††	-	-	1.52	1.04	2.47	1.68	5.90	3.08
Total score	-	-	0.17	0.16	0.08	0.18	0.41	0.40

* Policy on whether state requires or recommends that schools be prohibited from offering junk food in different settings
† Non-Hispanic
‡ The difference between BMI percentile among students in states that required/recommended schools to prohibit junk food and states that did not (referent), adjusted for student sex and state-level log per capita income, obesity prevalence, and political party of state legislature
§ SE: Standard error of difference
\# Likelihood ratio test for interaction between race/ethnicity and policy (degrees of freedom = 3)
** 'Recommend or require' compared to 'neither' (referent)
†† States the strengthened their policy (from 'neither' to 'recommend' or 'require,' or from 'recommend' to 'require') compared to states that reported 'neither' in both years (referent)

Appendix E: Association between policy change and BMI percentile, corrected for measurement error in height and weight

Table 17. Difference between non-Hispanic Whites and other racial/ethnic groups in the association between policy change and BMI percentile among 9th-12th grade students in 2007, corrected for measurement error in height and weight

	White†		Black†		Hispanic		Other†	
Setting	**Difference‡**	**SE§**	**Difference‡**	**SE§**	**Difference‡**	**SE§**	**Difference‡**	**SE§**
Vending machines								
Recommend or require	-	-	0.84	0.78	1.15	1.18	2.55	2.28
Require	-	-	0.81	0.81	0.83	1.45	3.58	2.66
Snack bars								
Recommend or require	-	-	1.05	0.73	0.98	1.16	3.47	2.01
Require	-	-	1.14	0.76	0.60	1.37	4.29	2.31
Concession stands**	-	-	0.37	0.75	-0.53	1.02	1.57	2.18
Parties**	-	-	0.64	0.69	-0.33	1.00	1.13	2.25
Breakfast/lunch††	-	-	1.22	0.75	1.80	1.21	4.06	2.08
Total score	-	-	-0.06	0.10	0.02	0.16	-0.32	0.29

* Policy on whether state requires or recommends that schools be prohibited from offering junk food in different settings
† Non-Hispanic
‡ The difference between BMI percentile among students in states that required/recommended schools to prohibit junk food and states that did not (referent), adjusted for student sex and state-level log per capita income, obesity prevalence, and political party of state legislature
§ SE: Standard error of difference
# Likelihood ratio test for interaction between race/ethnicity and policy (degrees of freedom = 3)
** 'Recommend or require' compared to 'neither' (referent)
†† States the strengthened their policy (from 'neither' to 'recommend' or 'require,' or from 'recommend' to 'require') compared to states that reported 'neither' in both years (referent)

Appendix F: Cross-sectional analysis of 2006 policies

Table 18. Racial/ethnic-specific association between 2006 state policies regarding junk food in schools* on student soda consumption among 9th-12th grade students in 2007

	White		Black		Hispanic		Other		
	Difference†	**SE**	**Difference†**	**SE**	**Difference†**	**SE**	**Difference†**	**SE**	**LR test‡**
Times (SSB)									
Recommend or require	0.02	0.05	0.03	0.07	0.03	0.09	-0.02	0.07	p=0.81
Require	0.05	0.05	-0.02	0.06	-0.02	0.08	-0.10§	0.05	p<0.001
Times (junk food)									
Recommend or require	-0.01	0.05	-0.09	0.07	0.02	0.07	-0.07	0.06	p=0.002
Require	0.01	0.05	-0.09	0.07	-0.01	0.08	-0.09	0.06	p<0.001
Fundraising									
Recommend or require	-0.05	0.05	-0.09	0.06	0.04	0.07	-0.02	0.06	p<0.001
Require	-0.01	0.07	-0.07	0.10	0.07	0.09	-0.12§	0.06	p<0.001
Fast food#	-0.06	0.05	-0.15	0.07	-0.18	0.10	0.01	0.07	p=0.002
Advertising#	-0.04	0.05	-0.04	0.06	0.10§	0.07	-0.07	0.06	p<0.001

* Times (SSB) – Restricting times when sugar-sweetened beverages can be sold
Times (junk food) – Restricting times when junk food can be sold
Fundraising – Prohibiting junk food from being sold for fundraising purposes
Fast food – Prohibiting brand-name fast food from being sold
Advertising – Prohibiting advertising of candy, fast food restaurants, or soft drinks

† The difference between daily servings of soda among students in states that required/recommended schools to prohibit junk food and states that did not (ref), adjusted for student sex and state-level log per capita income, obesity prevalence, and political party of state legislature

‡ Likelihood ratio test for interaction between race-ethnicity and policy (df = 3)

§ $p < 0.05$ for difference between racial/ethnic group and non-Hispanic Whites in the association between policy and soda consumption

\# 'Recommend or require' compared to 'neither' (ref)

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