Body Mass Transitions in Childhood and Early Adolescence: A Multistate Life Table Approach

Melanie K. Tran, MHPA[1]
Patrick M. Krueger, PhD[1]
Emily McCormick, MPH[2]
Arthur Davidson, MD, MSPH[2]
Deborah S. Main, PhD[1]

[1]University of Colorado Denver, Department of Health and Behavioral Sciences; and [2]Denver Public Health Department, Denver Health

Address correspondence to: Melanie Tran, University of Colorado, Denver, Campus Box 188, P.O. Box 173364, Denver, CO 80217-3364. Telephone: (303) 556-6796. Email: melanie.k.tran@ucdenver.edu.

Running title: Body Mass Transitions
Text: 4096 words
Abstract: 390 words
Tables: 3
Figures: 1

Grant Support: This paper was supported in part by a cooperative agreement with the Centers for Disease Control and Prevention (CDC) (#1U58DP003493-01 CO11). Portions of this project's work involve the Communities Transforming initiative supported by CDC funding. However, the findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the CDC.

Conflict of Interest: The authors declare that they have no conflict of interest.

ABSTRACT

Background: The growing prevalence of overweight and obesity among children and adolescents is well documented, with recent evidence suggesting this trend may be slowing down in some states. But prevalence estimates offer little insight into the rate of new cases of overweight or obesity, or the rate of "recovery" (i.e., transition to lower body mass statuses). We estimate the number of years children can expect to spend in the normal weight, overweight, or obese body mass statuses between ages 3 through 15, given their body mass status at age 3, by race/ethnicity and sex.

Methods: We use panel data with nurse-measured heights and weights among children aged 3 (pre-kindergarten) through 15 (9^{th} grade) from 2007 to 2013, in Denver Public Schools, and event-history models, to estimate age-, sex-, and race/ethnic-specific transition rates between normal weight, overweight, and obese statuses. Multistate life table methods allow us to estimate how many years children can expect to live in a given BMI status, conditional on their BMI at age 3, between ages 3 through 15.

Results: Children who are normal weight or obese at age 3 are relatively likely to remain in those statuses for the following 13 years. For example, children who are normal weight at age 3 can expect to spend 11.1 of the following 13 years in the normal weight status, and children who are obese at age 3 can expect to spend 9.8 of the following 13 years in the obese status. But, being overweight at age 3 is less "sticky": children who are overweight at age 3 can expect to spend 4.4 years in the normal weight status and 3.4 years in the obese status. We also find substantial race/ethnic disparities: whites and Asians tend to gravitate toward lower BMI statuses, regardless of their BMI status at age 3, whereas blacks and Mexicans tend to gravitate toward higher BMI statues.

Conclusions: Our findings show that being normal weight or obese at age three is highly predictive of BMI over the following 13 years. The prevention of obesity by age 3 may substantially benefit children throughout their lives. In contrast, being overweight at age 3 is less "sticky"—children routinely move out of that body mass category, and interventions may be relatively more successful at nudging children who are overweight at age 3 into a lower body mass status. We identify substantial race/ethnic disparities in the expect life spent in normal weight, overweight, and obese statuses, which suggests the need to better understand and target disparities in early life conditions that shape body mass in later life.

INTRODUCTION

The prevalence of overweight and obesity among children and adolescents in the United States has increased steadily over the past 30 years, with recent studies suggesting that trend may be reaching a plateau.[1,2] As of 2011-2012, 15% of children aged 2 to 19 were overweight and 17% were obese in the U.S.[2] Notably, the prevalence of obesity is higher among non-Hispanic blacks and Hispanics than among non-Hispanic whites and Asians, and is slightly higher among males than females, although sex differences in body mass vary substantially across race/ethnic groups.[2-5] Overweight and obesity in childhood has been linked to diabetes, cardiovascular disease, and premature mortality in adulthood.[6-10]

Most existing research focuses on the prevalence of overweight or obesity among children and adolescents or across race/ethnic and sex groups.[10,11] But prevalence estimates offer little insight into the rate of new cases of overweight or obesity, or the rate of "recovery" (i.e., transition to lower body mass statuses). Children and adolescents, however, are marked by rapid increases in height and weight due to growth, physical maturation, and behavioral factors including changing exercise and dietary patterns. Policies and interventions that seek to reduce excess body mass among children and adolescents could benefit from better understanding the number of years children and adolescents can expect to live in normal weight, overweight, or obese body mass statuses. Indeed, estimating the expected years spent in a given body mass status requires knowledge of the incidence of transitions to higher body mass categories (i.e., from normal weight to overweight, and from overweight to obese), as well as the incidence of "recovery" or transition to lower body mass categories (i.e., from obese to overweight, and from overweight to normal weight). We are aware of only three studies that have examined the incidence of obesity; they find that the incidence of obesity is higher among boys than among girls, and is higher among blacks than among whites and Hispanics.[11-13] Gordon-Larsen and colleagues[11] provide the only study that includes Asians and that estimates rates of recovery (i.e., transitions from obese to non-obese), but their study focuses on adolescents and young adults aged 13 to 26, and provide no insight into younger children. No existing studies estimate the number of years children can expect to be in specific body mass statuses.[11-13]

We aim to estimate the number of years children can expect to spend in the normal weight, overweight, or obese body mass statuses between ages 3 through 15, given their body mass status at age 3, by race/ethnicity and sex. Multistate life table methods allow us to use age-, sex-, and race/ethnic-specific rates of transition among body mass statuses to estimate the number of years lived in each body mass status. By allowing for recovery (i.e., transitions from higher to lower body masses), multistate life tables provide more valid estimates of the duration children can expect to remain in a given body mass status than models that only account for transitions to higher body mass statuses.[14,15]

METHODS

We use prospective panel data on a cohort of Denver Public School (DPS) pre-kindergarten through ninth grade students with height and weight measurements collected by school nurses during routine health assessment initiatives from 2007 to 2013. DPS is a large, race/ethnically diverse, urban school district serving over 87,000 students from pre-kindergarten through 12th grade in the 2013/2014 school year. Approximately 70% of DPS student's quality for the free and reduced lunch program for low-income students. Due to subsidized pre-kindergarten programs, children aged 5 and younger are representative of those who subsequently enroll in kindergarten in DPS, based on race/ethnicity, gender, and family income. DPS is among a handful of school districts nationally that have succeeded in systematically collecting longitudinal measures of height, weight, and, thus, body mass index (BMI).[16-19] The district uses these and other local data to help monitor and inform programs and policies to address childhood obesity.

Our study population consists of all students enrolled in at least two school years between Fall of 2007 and Spring of 2013 with at least two BMI observations. We include children aged 3 through 15 years who are non-Hispanic white, non-Hispanic black, non-Hispanic Asians, or Hispanic. We exclude 783 children who are in the 9th grade whose are aged 15 or older (e.g., a child who failed to advance) and who are not typical of all students aged 16 in DPS. Due to sample sizes that are too small to provide stable estimates, we exclude 448 American Indians/Alaskan Natives, 128 Native Hawaiians/Pacific Islanders, and 2,035 multiracial children. We exclude 10 observations that are considered implausible based on the 2000 CDC Growth Chart.[20] Our final sample is comprised of 65,672 students who average 2.7 height and weight measurements during the study period.

Variables

Our outcome variable is transitions among BMI categories (normal, overweight, obese). Nurses collect height and weight during routine hearing and vision screenings for pre-kindergarten, kindergarten, first, second, third, fifth, seventh and ninth grade students. Nurses use a standardized screening protocol to weigh and measure children and to record results in a school record database. We calculate BMI as kg/m^2 and we used a standardized SAS program to calculate BMI percentile and weight status. For each observation, we classify participants as normal weight if have a BMI below the 85th percentile, overweight if they have a BMI between the 85th and 95th percentiles, and obese if they have a BMI above the 95th percentile.[20]

Our predictor variables come from school records as reported by parents. Race/ethnicity is categorized as non-Hispanic White, non-Hispanic Black, non-Hispanic Asian, and Hispanic. Age at each observation is coded in months divided by 12. Sex is dichotomous.

Event History Analysis

We used discrete-time event history models to estimate annual incidence rates for transitions between normal weight, overweight, and obese statuses. Between sequential height and weight observations, respondents who occupy a given BMI status at the beginning of the interval are eligible to transition to a different BMI status at the subsequent observation. We created models to examine the three possible transitions. Model 1 predicts transitions from normal weight to overweight, Model 2 predicts transitions from overweight to either normal weight or obese, and Model 3 predicts transitions from obese to overweight (see Figure 1). A few students (0.60%) appeared to transition directly from normal weight to obese or from obese to normal weight between observations. We assume that those children transition to overweight halfway through the interval, before moving on to normal weight or obese, because transitions between normal weight and obese require a child be overweight sometime in the interim.

(Figure 1 about here)

To estimate our discrete time event-history models, we first created a person-month data set where each person contributes an observation for each month between two sequential height and weight observations or censoring (either on July 2013 or when they finish ninth grade). Next, we estimate our event history models in the person-month data with logistic regression for the risk of becoming overweight among those who are normal weight and the risk of becoming overweight among those who are obese, and with multinomial logistic regression for the risk of becoming either normal weight or obese among those who are overweight.[21]

In our models, age is a time-varying covariate that increases in each person-month. Because the risk of transition may vary non-linearly with age, we compare models that raise age to all combinations of one and then two of the following exponents: 0.5, 1, 1.5, 2, 2.5, and 3.[22] Raising age to the exponent of 0.5 best fit the data based on the Bayesian Information Criteria.[21] We also estimate models that test for all two-way and three-way interactions between age, race/ethnicity, and sex. We find support for models that include all two-way interactions (i.e., age by sex, age by race/ethnicity, and sex by race/ethnicity) but not three-way interactions. Interactions for age by race/ethnicity are significant in all models, although interactions for sex by race/ethnicity and sex by age are only significant in Model 1 and Model 3. Nevertheless, to preserve the same assumptions about the associations between the covariates and the outcomes across the models, we included interactions for sex by race/ethnicity and sex by age in Model 2.

Multistate Life Tables

We use multistate life table methods, and the age-, sex-, and race/ethnic-specific transition rates across BMI statuses from our event-history analysis, to calculate the number of years between ages 3 and the end of age 15 that individuals in a hypothetical cohort would spend in each of the weight status categories, conditional on weight status at baseline age.[23] Standard single-decrement life tables examine the number of years of expected life before making a single transition into an absorbing state (e.g., death). In contrast, multistate life tables allow people to transition back and forth across different non-absorbing states (e.g., normal weight, overweight, obese), although some individuals also transition into absorbing states such as death.[15] Although students must have at least two height and weight observations to be included in our analyses, very few students were observed continually from ages 3 through 15. Thus, our estimated transition rates incorporate both cohort (i.e., within individual) and period (i.e., between individuals over time) variability.[24]

Multistate life table calculations typically incorporate the risk of transitioning to death. Although mortality is rare among children aged 3 through 15, mortality rates at those ages vary substantially by age, sex, and race/ethnicity. Because DPS does not collect vital status on children, we use age-, sex-, and race/ethnicity-specific mortality rates from CDC WONDER.[25] We assumed that mortality rates are the same regardless of weight status at these ages because we are not aware of any estimates of the association between weight status and mortality among children aged 3 through 15. Thus, we use mortality rates from the U.S. population over the five-year period, 2006-2010, because five years provides stable estimates by single years of age and by race/ethnicity and sex, because 2010 is the most recent data available, and because the 2006-2010 data are centered over the years for which we have observations for height and weight. Appendix A presents the formulas for the calculation of the multistate life tables. We estimate 95% confidence intervals around our estimated life expectancies by simulating 5,000 sets of rates from our event-history models, calculating our multistate life tables for each set of values, and using the 2.5th centile and the 97.5th centile of our estimated life expectancies as the lower and upper bounds of our confidence intervals, respectively.[26]

Ethical issues

The institutional review board at the University of Colorado (Protocol No. 14-0970) approved this research. Parents consented for students to participate in vision and hearing screening and to have weight and height measured.

RESULTS

Table 1 presents descriptive statistics for the person-month data, by the child's BMI status at the beginning of each month (across the top of the table). Children who are normal weight at the beginning of a given person month are more likely to be younger, female, white, Asian, or black than are children who are overweight or obese at the beginning of a given person month. Table 1 also presents the distribution of BMI statuses at the end of each person-month, across BMI values at the beginning of each person-month. The first column shows that 99.7% of children who are normal weight at the beginning of a given person-month remain in the normal weight status at the end of the person-month, with 0.3% becoming overweight by the end of the month. Among children who are overweight at the beginning of a given person month, 2.4% become normal weight by the end of the month and 0.8% become obese by the end of the month. Finally, among children who are obese at the end of a given person month, 1.4% become normal weight. Children are normal weight at the beginning of about 70% of the person months, overweight at the beginning of 15% of person months, and are obese at the beginning of about 15% of the person months.

(Table 1 about here)

Table 2 presents the discrete time event-history models. Model 1 examines the risk of becoming overweight among those are normal weight. For example, the hazard ratio for age raised to the exponent of 0.5 shows that, among white females, the risk of becoming overweight among those who are normal weight increases with age, although that association is stronger at younger ages. Specifically, white females at age 4 have 1.15 (=[$4^{0.5}$*1.67]/ [$3^{0.5}$*1.67]) times the risk of becoming overweight as white females at age 3, although white females at age 15 have just 1.04 (=[$15^{0.5}$*1.67]/ [$14^{0.5}$*1.67]) times the risk of becoming obese as white females at age 14. Further, Model 1 shows significant variation in the risk of becoming overweight by age, sex, and race/ethnicity, and finds significant interactions for age by race/ethnicity, sex by race/ethnicity, and sex by age. Model 2 examines the risk of becoming normal weight or obese among those who are overweight, and model 3 examines the risk of becoming overweight among those who are obese. The purpose of our event-history analyses is to estimate age-, sex-, and race/ethnic-specific rates of transition among BMI statuses as the basis of our multistate life table analyses. Rather than interpreting the hazard ratios in models with multiple interaction terms, we turn to the multistate life tables estimates that more simply summarize race/ethnic and sex differences.

(Table 2 about here)

Table 3 shows life expectancies for the number of years children who are normal weight, overweight, or obese at age 3 can expect to spend in a given BMI status by the end of age 15. The first row shows life expectancies for children of both sexes and all race/ethnic groups, combined. Children who are normal weight at age 3 can expect to spend most (11.1 years) of the following 13 years in the normal weight status, only 1.3 years in the overweight status, and just 0.6 years in the obese status. Conversely, children who are overweight at age 3 can expect to spend more than half of the following 13 years in either the normal weight status (4.4 years) or the obese status (3.4 years). Children who are obese at age 3, however, can expect to spent most (9.8 years) of the following 13 years in the obese status, and just 2.1 years in the overweight status and 1.1 years in the normal weight status.

(Table 3 about here)

The remaining rows on Table 3 show life expectancy estimates separately by sex, by race/ethnicity, and by race/ethnicity and sex. Three major patterns emerge. First, whites and Asians generally spend more of their years in the normal weight status, if they are normal weight at age 3, than children in other race/ethnic groups. Whites and Asians who are normal weight at age 3 can expect to spend about 12 of the following 13 years in the normal weight status. By comparison, blacks and Hispanics who are normal weight at age 3 can expect to spend about 11.0 years and 10.6 years, respectively, in the normal weight status.

Second, whites who are overweight or obese at age 3 spend more years than males or females in other race/ethnic groups in lower BMI statuses. For example, whites who are overweight at age three can expect to live nearly 7 years of the following 13 years in the normal weight status, and just 1.4 of the following 13 years in the obese status. Further, whites who are obese at age 3 can expect to spend 3.3 of the following 13 years in the overweight status and another 3.1 years in the normal weight status. In contrast, blacks and Hispanics are relatively more likely to spend time in higher BMI statuses. Black and Hispanic children who are overweight at age 3 can expect to spend 3.4 years and 3.9 years, respectively, in the obese status. Further, Black and Hispanic children who are obese at age 3 are can expect to spend just 1.4 years and 0.9 years, respectively, in the normal weight status.

Finally, sex differences in the expected number of years spent in a given BMI status vary substantially by race/ethnicity. White males and white females have substantively similar life expectancies in each status. Among Asians, females generally spend more years in lower statuses than males, regardless of the BMI status at age 3. The opposite pattern emerges among blacks: regardless of the BMI status at age 3, black females tend to spend more of the following 13 years in higher BMI statuses than black males. Finally, sex differences among Hispanics are more subtle. Hispanic females who are normal weight or overweight at age 3, can expect to spend relatively fewer of the following 13 years in the obese status than Hispanic females, but among Hispanic children who are obese at age 3, we observe substantially similar life expectancies.

DISCUSSION

Our paper is the first to report the number of years that children can expect to spend in specific BMI statuses, between the ages of 3 through 15. Indeed, ## important findings emerge. First, being normal weight or obese at age 3 is highly predictive of future weight status. In general, children who are normal weight at age 3 can expect to spend 11 of the following 13 years in the normal weight status, and children who are obese at age 3 can expect to spend 9.8 of the following 13 years in the obese status. Nutritional and exercise behaviors, as well as post-natal factors, may have a strong influence on body mass among children throughout childhood and adolescence, and perhaps even into adulthood. The fact that body mass status at age 3 is so strongly tied to body mass status into adolescence suggests the need to better understand the social and behavioral etiology of BMI among very young children.

Second, however, being overweight at age 3 confers only modest insight into BMI over the following 13 years. In our population based sample, children who were overweight at age 3 could expect to spend 4.4 of the following 13 years in the normal weight status, 5.1 years in the overweight status, and 3.4 years in the obese status. For children who are overweight at age 3, BMI is somewhat dynamic. Interventions that successfully target children who are overweight at age 3 may be particularly effective at nudging children into healthier BMI statuses into adolescence.

Finally, we identify substantially race/ethnic and sex differences in the number of years children can expect to live in a given BMI status. Relative to others, whites of both sexes and Asian females shift to lower BMI statuses—they are most likely to stay in the normal weight status if they are normal weight at age 3, and they spend relatively more time in lower BMI statuses if they are overweight or obese at age 3. In contrast, blacks and Hispanics of both sexes are relatively more likely to gravitate to higher BMI statuses—they are least likely to leave the obese status if they are obese at age 3, and they are most likely to transition to higher BMI statuses if they are normal weight or overweight at age 3. Asian males occupy a middle position—if they are normal weight at age 3, they can expect to spend more years in the overweight and obese statuses than Asian females or whites, but if they are obese at age 3, Asian males Can expect to spend fewer years in the obese status than Hispanics of either sex or black females. Our results suggest important race/ethnic differences in the incidence of transitions to higher BMI statuses as well as in recovery, or transitions to lower BMI statuses. Public health research may benefit from efforts to identify interventions that prevent increases in BMI as well as interventions that increase reductions in BMI. Those efforts may be most successful if they target the different social and behavioral circumstances that inform race/ethnic and sex disparities.

Our study has several important strengths, including six years of cohort data that allow us to estimate age-specific transitions across BMI statuses, for ages 3 through 15, by race/ethnicity and sex. Most nationally representative data that have been used to study the incidence of obesity focus on older age groups or cover a smaller subset of age-ranges.[11-13] Our study demonstrates the value of working with school systems to acquire data that is representative and accurate. Further, we use multistate life tables to estimate how long children can expect to spend in a given BMI status; a method that has been used to examine multiregional migration patterns or active life expectancy among the elderly, but that have not been used to examine BMI among children.[14,15] Significantly, our analyses specifically account for the rate of transitions to higher BMI statuses, but also recovery, or transitions to lower BMI statuses.

Several limitations of our data also warrant mention. First, our data come from Denver Public Schools, and may not be representative of children in the United States more broadly, or even of all children in Denver, Colorado. Some recent research suggests that the prevalence of obesity has stabilized or declined among younger age groups,[1,2] although Colorado remains one of the states with an increasing prevalence of obesity. Nevertheless, the patterns we observe in our study are consistent with existing evidence on the incidence and prevalence of obesity, with higher rates of obesity among blacks and Hispanics than among whites or Asians.[2-5] Second, our data were collected by school nurses, which may result in greater error in the measurement of height and weight than if trained researchers had been used. But, to minimize data collection errors, nurses followed a standardized protocol. Third, our approach focuses on discrete and meaningful BMI statuses (i.e., normal weight, overweight, and obese), so some students may experience increases or decreases in BMI that are not captured in our study if they do not result in movement between BMI statuses.

Conclusion

Our findings emphasize the importance of identifying prevention and intervention strategies that target elevated body mass among pre-school aged children. Interventions may be particularly effective if they target children who are overweight by age 3—those children might be most easily nudged into lower BMI statuses. In contrast, prevention of obesity may be more effective than treatment before age 3. Our results show that obesity is a relatively “sticky” status even at age 3, as such, interventions that target children who are obese at age 3 may be less effective than interventions that target overweight children. Nevertheless, reducing the share of children who are obese by age 3 may have particularly substantial benefits for reductions in diabetes and cardiovascular disease in the future.[6-10] Further, investments in children’s health in early life may result in saved health care costs throughout childhood and potentially into adulthood. Thus, the prevention of obesity at very early ages may result in substantial dividends for health for years into the future.

ACKNOWLEDGMENTS

We would like to acknowledge the support from the Denver Public Schools team of Bridget Beatty, Scott Romero, and Donna Shocks that enabled us access to the dataset and the University of Colorado Denver College of Liberal Arts and Sciences Research Innovation Seed Program (CRISP) award for providing additional funding for the research. The authors are grateful to the Centers for Disease Control and Prevention and to ICF International for support during the writing training, to Dr. George Rutherford for writing assistance. We thank Jani Little and Frank Witmer at Computing and Research Services at the Institute of Behavioral Sciences at the University of Colorado, Boulder, for help with statistical analysis, and acknowledge the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) funded University of Colorado Population Center (grant R24 HD066613) for administrative support.

REFERENCES

1. Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999-2000. *Journal of the American Medical Association.* 2002;288:1728-1732.
2. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the united states, 2011-2012. *JAMA.* 2014;311(8):806-814.
3. Singh GK, Kogan MD, Van Dyck PC, Siahpush M. Racial/Ethnic, Socioeconomic, and Behavioral Determinants of Childhood and Adolescent Obesity in the United States: Analyzing Independent and Joint Associations. *Annals of Epidemiology.*18(9):682-695.
4. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of obesity and trends in body mass index among us children and adolescents, 1999-2010. *JAMA.* 2012;307(5):483-490.
5. Wang YC, Gortmaker SL, Taveras EM. Trends and racial/ethnic disparities in severe obesity among US children and adolescents, 1976–2006. *International Journal of Pediatric Obesity.* 2011;6(1):12-20.
6. Baker JL, Olsen LW, Sørensen TIA. Childhood Body-Mass Index and the Risk of Coronary Heart Disease in Adulthood. *New England Journal of Medicine.* 2007;357(23):2329-2337.
7. Farhat T, Iannotti RJ, Simons-Morton BG. Overweight, Obesity, Youth, and Health-Risk Behaviors. *American Journal of Preventive Medicine.*38(3):258-267.
8. Reilly JJ, Kelly J. Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: systematic review. *Int J Obes.* 07//print 2011;35(7):891-898.
9. Dietz WH. Critical periods in childhood for the development of obesity. *American Journal of Clinical Nutrition.* 1994;59:955-959.
10. Field AE, Cook NR, Gillman MW. Weight Status in Childhood as a Predictor of Becoming Overweight or Hypertensive in Early Adulthood**. *Obesity Research.* 2005;13(1):163-169.
11. Gordon-Larsen P, Adair LS, Nelson MC, Popkin BM. Five-year obesity incidence in the transition period between adolescence and adulthood: the National Longitudinal Study of Adolescent Health. *The American Journal of Clinical Nutrition.* 2004;80:569-575.
12. Strauss RS, Knight J. Influence of the home environment on the development of obesity in children. *Pediatrics.* 1999;103:85-93.
13. Cunningham SA, Kramer MR, Narayan KMV. Incidence of childhood obesity in the United States. *N Engl J Med.* 2014;370(5):403-411.
14. Nusselder WJ, Peeters A. Successful aging: measuring the years lived with functional loss. *J Epidemiol Community Health.* 2006;60:448-455.
15. Rogers A. *Multiregional demography: principles, methods, and extensions.* New York, NY: John Wiley & Sons; 1995.
16. Thompson JW, Card-Higginson P. Arkansas' experience: statewide surveillance and parental information on the child obesity epidemic. *Pediatrics.* 2009;124(Supplement 1):S73-S82.
17. Longjohn M, Sheon AR, Card-Higginson P, Nader PR, Mason M. Learning from state surveillance of childhood obesity. *Health Affairs.* 2010;29(3):463-472.
18. Robbins JM, Mallya G, Polansky M, Schwarz DF. Peer Reviewed: Prevalence, Disparities, and Trends in Obesity and Severe Obesity Among Students in the

Philadelphia, Pennsylvania, School District, 2006–2010. *Preventing chronic disease.* 2012;9.
19. Nihiser AJ, Lee SM, Wechsler H, et al. BMI measurement in schools. *Pediatrics.* 2009;124(Supplement 1):S89-S97.
20. Kucsmarski R, Ogden C, Guo S. 2000 CDC growth charts for the United States: Methods and development. *National Center for Health Statistics. Vital and Health Statistics.* 2002;11(246):1-190.
21. Singer JD, Willett JB. *Applied longitudinal data analysis: modeling change and event occurrence.* New York: Oxford University Press; 2003.
22. Greenland S. Dose-response and trend analysis in epidemiology: alternatives to categorical analysis. *Epidemiology.* 1995;6:356-365.
23. *Stata Statistical Software: Release 11* [computer program]. College Station, TX: StataCorp LP; 2009.
24. Preston SH, Heuveline P, Guillot M. *Demography: measuring and modeling population processes.* Malden, MA: Blackwell; 2001.
25. Centers for Disease Control and Prevention National Center for Health Statistics. Underlying cause of death 1999-2010 on CDC WONDER online database, released 2012. 2014, Accessed at http://wonder.cdc.gov/ucd-icd10.html on Feb 20, 2014
26. King G, Tomz M, Wittenberg J. Making the most of statistical analyses: improving interpretation and presentation. *Am J Pol Sci.* 2000;44(2):341-355.

Figure 1: Transitions examined among respondents aged 3 to 15, 2007 to 2013.

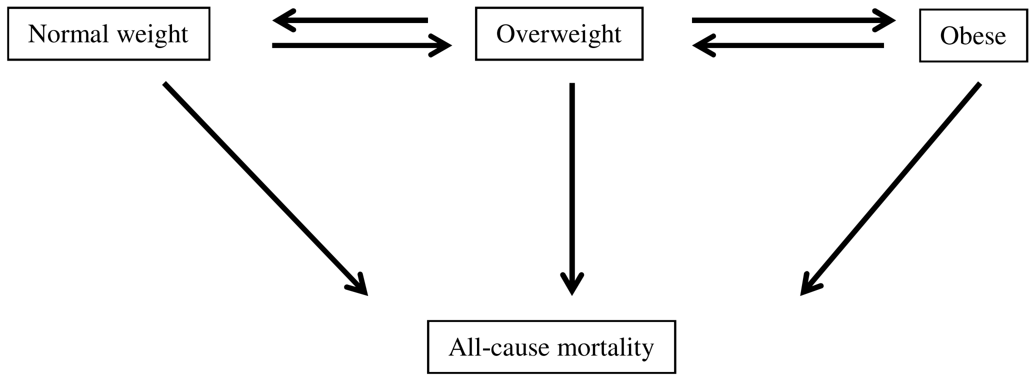

Table 1: Descriptive statistics for children aged 3 through 15, Denver Public Schools, 2007-2013

	BMI status at the beginning of each person-month		
	Normal weight	Overweight	Obese
Age in years, mean (std. dev.)	8.7 (2.7)	9.3 (2.8)	9.6 (2.8)
Sex			
Female	51.2%	49.6%	42.8%
Male	48.8%	50.4%	57.2%
Race/ethnicity			
White	23.4%	12.7%	6.6%
Asian	3.6%	2.5%	1.8%
Black	12.5%	12.1%	10.5%
Hispanic	60.5%	72.7%	81.1%
BMI status at the end of each person-month			
Normal weight	99.7%	2.4%	-
Overweight	0.3%	96.7%	1.4%
Obese	-	0.8%	98.6%
N (person)	44,453	10,215	11,004
N (person-months)	1,202,399	264,155	273,321

Note: Normal: <85th percentile, Overweight: 85th-95th percentile, Obese: >95th percentile

Table 2: Hazard ratios and 95% confidence intervals from discrete-time event history models of transitions in BMI, Denver Public Schools, 2007-2013

	Model 1§	Model 2¶		Model 3§
	Normal to overweight	Overweight to normal	Overweight to obese	Obese to overweight
$Age^{0.5}$	1.67***	0.59***	1.23	0.57***
	(1.42 - 1.97)	(0.48 - 0.73)	(0.99 - 1.54)	(0.42 - 0.79)
Sex				
Female	1.00	1.00	1.00	1.00
Male	2.28***	0.90	1.43	1.74
	(1.62 - 3.22)	(0.56 - 1.47)	(0.91 - 2.23)	(0.87 - 3.46)
Race/ethnicity				
White	1.00	1.00	1.00	1.00
Asian	1.69	0.40	9.06**	0.12*
	(0.56 - 5.13)	(0.09 - 1.73)	(2.22 - 36.96)	(0.02 - 0.77)
African-American	4.19***	0.41*	3.31**	0.30
	(2.20 - 7.99)	(0.17 - 1.00)	(1.37 - 7.98)	(0.08 - 1.16)
Hispanic	5.83***	0.39**	3.92***	0.07***
	(3.53 - 9.63)	(0.21 - 0.72)	(1.91 - 8.01)	(0.03 - 0.20)
Interactions				
$Age^{0.5}$ by race/ethnicity				
Asian	0.87	1.41	0.50**	2.18*
	(0.61 - 1.23)	(0.88 - 2.26)	(0.32 - 0.78)	(1.19 - 3.98)
African-American	0.83	1.22	0.82	1.16
	(0.68 - 1.03)	(0.90 - 1.64)	(0.62 - 1.09)	(0.75 - 1.79)
Hispanic	0.74***	1.22	0.74**	1.90***
	(0.63 - 0.87)	(0.99 - 1.50)	(0.59 - 0.92)	(1.37 - 2.63)
Male sex by race/ethnicity				
Asian	1.26	0.67	1.33	0.79
	(0.89 - 1.79)	(0.44 - 1.01)	(0.80 - 2.20)	(0.46 - 1.36)
African-American	0.64***	0.97	0.72*	1.49*
	(0.53 - 0.78)	(0.75 - 1.24)	(0.54 - 0.96)	(1.03 - 2.16)
Hispanic	0.91	0.97	1.03	1.01
	(0.78 - 1.06)	(0.82 - 1.16)	(0.82 - 1.30)	(0.77 - 1.34)
Male by $age^{0.5}$	0.82***	1.09	0.94	0.80*
	(0.74 - 0.91)	(0.93 - 1.28)	(0.83 - 1.07)	(0.64 - 1.00)
Constant	0.00***	0.79	0.04***	0.65
	(0.00 - 0.01)	(0.43 - 1.45)	(0.02 - 0.09)	(0.25 - 1.74)

Note: *** p<0.001, ** p<0.01, * p<0.05, § logistic regression, ¶ multinomial regression

Table 3: Life expectancy in each BMI status at ages 3 through 15, conditional on BMI at age 3, by race/ethnicity and sex, Denver Public Schools, 2007-2013

	Weight status at age 3:								
	Normal weight			Overweight			Obese		
	Normal weight	Overweight	Obese	Normal weight	Overweight	Obese	Normal weight	Overweight	Obese
Overall	11.1	1.3	0.6	4.4	5.1	3.4	1.1	2.1	9.8
	(11.1 - 11.2)	(1.2 - 1.3)	(0.5 - 0.6)	(4.2 - 4.6)	(5.0 - 5.2)	(3.3 - 3.6)	(1.0 - 1.2)	(2.0 - 2.2)	(9.7 - 10.0)
Females	11.3	1.2	0.5	4.5	5.3	3.2	1.0	2.1	9.8
	(11.2 - 11.3)	(1.2 - 1.3)	(0.4 - 0.5)	(4.2 - 4.8)	(5.1 - 5.5)	(3.0 - 4.8)	(0.9 - 1.1)	(2.0 - 2.3)	(9.6 - 10.1)
Males	11.0	1.4	0.6	4.3	5.0	3.7	1.1	2.0	9.9
	(10.9 - 11.1)	(1.3 - 1.4)	(0.6 - 0.7)	(4.1 - 4.6)	(4.8 - 5.1)	(3.5 - 3.9)	(1.0 - 1.2)	(1.9 - 2.2)	(9.6 - 10.1)
White	12.1	0.7	0.2	6.9	4.7	1.4	3.1	3.3	6.6
	(12.0 - 12.1)	(0.7 - 0.8)	(0.2 - 0.2)	(6.4 - 7.3)	(4.4 - 5.0)	(1.2 - 1.7)	(2.7 - 3.6)	(3.0 - 3.6)	(5.9 - 7.3)
Females	12.2	0.7	0.1	6.9	4.8	1.3	3.0	3.4	6.6
	(12.1 - 12.2)	(0.6 - 0.8)	(0.1 - 0.2)	(6.3 - 7.4)	(4.4 - 5.2)	(1.0 - 1.7)	(2.4 - 3.6)	(2.9 - 3.8)	(5.6 - 7.6)
Males	12.0	0.8	0.2	6.9	4.6	1.5	3.2	3.2	6.6
	(11.9 - 12.1)	(0.7 - 0.9)	(0.2 - 0.3)	(6.4 - 7.4)	(4.2 - 4.9)	(1.3 - 1.9)	(2.7 - 3.7)	(2.8 - 3.5)	(5.9 - 7.4)
Asian	11.8	0.9	0.3	4.8	5.1	3.1	1.9	3.0	8.2
	(11.7 - 11.9)	(0.8 - 0.9)	(0.3 - 0.3)	(4.4 - 5.3)	(4.9 - 5.2)	(2.8 - 3.3)	(1.6 - 2.4)	(2.8 - 3.3)	(7.5 - 8.7)
Females	12.1	0.8	0.2	5.7	5.0	2.3	2.3	3.2	7.5
	(11.8 - 12.3)	(0.6 -1.0)	(0.1 - 0.3)	(4.3 - 7.2)	(4.1 - 5.9)	(1.4 - 3.4)	(1.6 - 3.3)	(2.5 - 3.9)	(6.0 - 8.8)
Males	11.3	1.2	0.5	3.9	5.0	4.1	1.5	2.8	8.8
	(10.9 - 11.7)	(0.9 - 1.4)	(0.4 - 0.7)	(2.8 - 5.2)	(4.3 - 5.7)	(3.0 - 5.3)	(1.0 - 2.1)	(2.2 - 3.5)	(7.6 - 9.7)
Black	11.0	1.4	0.6	4.4	5.2	3.4	1.4	2.5	9.1
	(10.9 - 11.0)	(1.3 - 1.5)	(0.6 - 0.6)	(4.0 - 4.8)	(4.9 - 5.5)	(3.1 - 3.8)	(1.0 - 1.8)	(2.2 - 2.8)	(8.6 - 9.5)
Females	10.8	1.5	0.7	4.1	5.2	3.7	1.1	2.1	9.8
	(10.6 - 11.0)	(1.3 - 1.6)	(0.6 - 0.8)	(3.5 - 4.8)	(4.8 - 5.6)	(3.2 - 4.3)	(0.8 - 1.4)	(1.8 - 2.6)	(9.1 - 10.4)
Males	11.2	1.3	0.5	4.6	5.3	3.1	1.7	2.8	8.5
	(11.0 - 11.3)	(1.2 - 1.4)	(0.5 - 0.6)	(4.0 - 5.3)	(4.9 - 5.7)	(2.6 - 3.6)	(1.4 - 2.1)	(2.4 - 3.2)	(7.7 - 9.2)
Hispanic	10.6	1.6	0.8	3.9	5.2	3.9	0.9	1.9	10.2
	(10.5 - 10.7)	(1.6 - 1.6)	(0.8 - 0.9)	(3.8 - 4.2)	(5.1 - 5.3)	(3.7 - 4.1)	(0.8 - 1.0)	(1.8 - 2.1)	(10.0 - 10.4)
Females	10.8	1.5	0.6	4.0	5.4	3.6	0.9	2.0	10.1
	(10.7 - 10.9)	(1.5 - 1.6)	(0.6 - 0.7)	(3.8 - 4.3)	(5.2 - 5.6)	(3.3 - 3.8)	(0.8 - 1.0)	(1.9 - 2.2)	(9.9 - 10.4)
Males	10.4	1.7	0.9	3.8	5.0	4.2	0.9	1.8	10.3
	(10.3 - 10.5)	(1.6 - 1.7)	(0.8 - 0.9)	(3.5 - 4.1)	(4.8 - 5.1)	(3.9 - 4.5)	(0.8 - 1.0)	(1.7 - 2.0)	(10.0 - 10.4)

APPENDIX

We use the annual age-specific transition rates across BMI categories (estimated from our event-history models), and annual age-specific mortality rates, to calculate the multistate life tables. We use matrix algebra notation throughout the appendix to simplify our presentation of the calculations. First, we create a transition matrix to describe transitions across statuses:

$\boldsymbol{M}(x) =$

$$\begin{bmatrix} m_{1d}(x) + m_{12}(x) + m_{13}(x) & -m_{21}(x) & -m_{31}(x) \\ -m_{12}(x) & m_{2d}(x) + m_{21}(x) + m_{23}(x) & -m_{32}(x) \\ -m_{13}(x) & -m_{23}(x) & m_{3d}(x) + m_{31}(x) + m_{32}(x) \end{bmatrix}$$

where $\boldsymbol{M}(x)$ is the matrix of transition rates, $m_{1d}(x)$ is the transition rate from status 1 (normal weight) to death, $m_{12}(x)$ is the transition rate from status 1 (normal weight) to status 2 (overweight), $m_{13}(x)$ is the transition rate from status 1 (normal weight) to status 3 (obese), and (x) denotes the age interval x to $x+1$, given that we use 1-year age intervals throughout. The notation for the transition rates for individuals starting in status 2 or 3 follows from those already described. The transition rates between normal weight and obese statuses (i.e., $m_{13}(x)$ and $m_{31}(x)$) are set to 0, because respondents are only at risk of becoming normal weight or obese if they are in the overweight status.

Next we estimate transition probabilities from our transition rates, using the linear assumption described in Rogers 1995:

$$\boldsymbol{P}(x) = \left[\boldsymbol{I} + \tfrac{1}{2}\boldsymbol{M}(x)\right]^{-1}\left[\boldsymbol{I} - \tfrac{1}{2}\boldsymbol{M}(x)\right] \qquad \text{(eq. 1)}$$

Where $\boldsymbol{P}(x)$ is the transition probability matrix, $\boldsymbol{I}$ is the identity matrix, and $\boldsymbol{M}(x)$ is the matrix of transition rates described above. The transition probabilities describe the probability that individuals in state i at exact age x will survive and live in state j exactly one year later.

The matrix $\boldsymbol{l}(x)$ contains the number of survivors in each state at exact age x. For age 3 (the first age that we consider in our data), we follow standard practice and set the radix to 100,000:

$$\boldsymbol{l}(3) = \begin{bmatrix} 100{,}000 & 0 & 0 \\ 0 & 100{,}000 & 0 \\ 0 & 0 & 100{,}000 \end{bmatrix}$$

For the remaining ages, we calculate the number of survivors in each state at age $x + 1$ by multiplying the probability that individuals in state i at exact age x will survive and live in state j one year later, by the number of survivors in each state at age x:

$$\boldsymbol{l}(x+1) = \boldsymbol{P}(x)\boldsymbol{l}(x) \qquad \text{(eq. 2)}$$

Next, we calculate the matrix $\boldsymbol{L}(x)$ which indicates the number of person years lived in each state:

$$\boldsymbol{L}(x) = \frac{1}{2}[\boldsymbol{I} + \boldsymbol{P}(\boldsymbol{x})]\boldsymbol{l}(x) \qquad \text{(eq. 3)}$$

Researchers often use the following equation to calculate $\boldsymbol{L}(z)$, where (z) is the age at the beginning of the oldest (e.g., open-ended) age interval:

$$\boldsymbol{L}(z) = \boldsymbol{M}(z)^{-1}\boldsymbol{l}(z) \qquad \text{(eq. 4)}$$

However, in our case, the life years lived in the open-ended category will be excessively large (resulting in an implausibly large life expectancy) because equation 4 assumes that the mortality rates for in the open-ended category is constant (rather than increasing) in the open-ended age group (see Rogers 1995). Instead, we calculate $\boldsymbol{L}(z)$ as follows. First, we use our event-history models to forecast transition rates across the BMI statuses to age 16, and use mortality rates from CDC Wonder through age 16. Then, we apply equations 1 through 3 to our data for ages 3 through 16, and drop those aged 16 in all subsequent steps of the multistate life table calculations. As a result, our estimated life expectancies show the expected number of years between the beginning of age 3 and the end of year 15 than individuals can expect to live in each state.

We calculate $\boldsymbol{T}(x)$, or the expected number of person years lived after age x in a given state, as:

$$\boldsymbol{T}(x) = \sum_{x}^{z} \boldsymbol{L}(x) \qquad \text{(eq. 5)}$$

Thus, at any given age x, $\boldsymbol{T}(x)$ is the sum of $\boldsymbol{L}(x)$ from age x through the final age z. By implication, $\boldsymbol{T}(z) = \boldsymbol{L}(z)$.

Finally, we calculate the expected number of years lived in each state, conditional on the current BMI status at age x, as:

$$\boldsymbol{e}(x) = \boldsymbol{T}(x)\boldsymbol{l}(x)^{-1} \qquad \text{(eq. 6)}$$

As noted above, our life expectancies at age 3 add up to 13 years (minus any time spent in the “absorbing” state of death), from the beginning of age 3 to the end of age 15.