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The Contribution of Differences in Adiposity to Educational Disparities in Mortality in the United States

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Abstract

Background: There are large differences in life expectancy by educational attainment in the United States. Previous research has found obesity's contribution to these differences to be small. Those findings may be sensitive to how obesity is estimated. Methods: This analysis uses discrete time logistic regressions with data from the National Health and Nutrition Examination Survey (NHANES), pooled from 1988-1994 and 1999-2010, to estimate the contribution of differences in adiposity, or body fat, to educational differences in mortality. I show that results depend upon the measure of adiposity used: body mass index (BMI) at survey or lifetime maximum BMI. Results: High school graduates had higher BMIs at time of survey than college graduates (28.6 vs 27.3, respectively), as well as higher maximum BMIs (30.8 vs 29.1, respectively. Lifetime maximum BMI performed better than BMI at survey time in predicting mortality using criteria for model selection. Differences in maximum BMI were associated with 9.2% of educational mortality differences, compared to 2.2% for BMI at survey. Among non-smokers, 15.8% of the differential was associated with differences in maximum BMI. Contribution: Adiposity is an overlooked contributor to educational differences in mortality. Previous findings that obesity does not contribute to educational disparities were based on BMI at survey, which is less informative than maximum BMI. The contribution of adiposity to educational mortality differences will likely grow as smoking prevalence declines. Health surveys should collect information on weight history.

Keywords

obesity, education, mortality

Disciplines

Demography, Population, and Ecology | Food Studies | Medicine and Health Sciences | Nutritional and Metabolic Diseases | Public Health | Social and Behavioral Sciences | Sociology

Comments

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The contribution of differences in adiposity to educational disparities in mortality in the United States

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ABSTRACT

Background: There are large differences in life expectancy by educational attainment in the United States. Previous research has found obesity's contribution to these differences to be small. Those findings may be sensitive to how obesity is estimated.

Methods: This analysis uses discrete time logistic regressions with data from the National Health and Nutrition Examination Survey (NHANES), pooled from 1988-1994 and 1999-2010, to estimate the contribution of differences in adiposity, or body fat, to educational differences in mortality. I show that results depend upon the measure of adiposity used: body mass index (BMI) at survey or lifetime maximum BMI.

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Contribution: Adiposity is an overlooked contributor to educational differences in mortality. Previous findings that obesity does not contribute to educational disparities were based on BMI at survey, which is less informative than maximum BMI. The contribution of adiposity to educational mortality differences will likely grow as smoking prevalence declines. Health surveys should collect information on weight history.

Contents

1. Introduction

1.1 The socio-economic gradient in mortality

Life expectancy and disease patterns follow a well-documented socio-economic gradient in many high-income countries (see e.g., Elo 2009; Hayward et al. 2015; Laditka and Laditka 2016; Mackenbach et al. 2008). Between 1999 and 2011, for example, life expectancy for a 40 year-old college-educated white woman in the United States was 42.7 years, compared to 29.6 years for a white woman with less than a 9^{th}-grade education (Laditka and Laditka 2016). Substantial disparities in mortality rates by educational attainment have similarly been observed in many European countries (Mackenbach et al. 2008). Recent evidence suggests that differentials in the United States and elsewhere may be widening (see, e.g., Mackenbach et al. 2015; National Academies of Sciences, Engineering, and Medicine 2015), adding further urgency to an already urgent issue.

An extensive body of research seeks to identify the mechanisms driving the relationship between education and mortality. One branch of this work focuses on the impact of modifiable health behaviors, such as smoking, alcohol and drug use, and obesity. Obesity, defined as having a body mass index (BMI) of 30 or greater, is a salient factor in view of the growing prevalence of obesity in many countries (Devaux and Sassi 2013; Flegal et al. 2007; Ogden et al. 2010; Ogden et al. 2015; Robertson et al. 2007), a global trend that is well-illustrated in the United States (World Health Organization 2016; Finucane et al. 2011). In 1980, for example, 16% of US women and 12% of US men were considered obese, compared to 36% of women and 34% of men in 2014 (World Health Organization 2016). Though obesity rates have increased for all segments of the US population in recent decades, poorer and less educated people continue to be more likely to be obese (Chang and Lauderdale 2005; Ogden et al. 2010; Yu 2012), an association that may have strengthened during the Great Recession (Wang et al. 2016). Given the health and mortality risks associated with obesity, growing educational disparities in obesity prevalence could exacerbate existing mortality differentials. Obesity influences health and mortality through a variety of channels, such as by increasing the risk of diabetes (Abdullah et al. 2011), cardiovascular diseases (Tarleton et al. 2014), cancer (Wolin et al. 2010), and disability (Alley and Chang 2007; Mehta and Chang 2009; Reynolds et al. 2005). Stokes and Preston (2016) estimate that nearly one in six deaths occurring in the United States between 1988 and 2004 can be attributed to obesity.

Despite the health implications of obesity and its possibly strengthening inverse relationship with socio-economic status, obesity and more generally, adiposity, or body fat, has not been adequately examined as a determinant of socio-economic mortality differentials in the United States. Surprisingly, research that has explored this topic, such as the work on health behaviors by Mehta et al. (2015) or Montez and Zajacova (2013), finds no significant contribution of adiposity to socio-economic differences in mortality. It is possible that these and other findings are sensitive to bias in estimating the mortality consequences of obesity, as outlined in section 1.2 below.

1.2 A better way to measure adiposity in studies on mortality disparities

Prior studies on health behaviors and socio-economic status commonly estimate adiposity using one cross-sectional observation of BMI, a weight-to-height ratio calculated as weight in kilograms over height in meters squared. BMI at time of survey can be a problematic measure in estimating the relationship between adiposity and mortality because it is susceptible to bias from reverse causation due to illness. This can occur when formerly obese individuals lose weight due to an illness prior to participating in the survey. Although these individuals may present a healthy BMI at survey time, their risk of mortality is elevated due to the underlying illness. This process artificially inflates mortality rates for lower BMI ranges and decreases mortality rates for higher ranges since ill individuals have been selected out of the obese population (Stokes and Preston 2016; Stokes 2014; Stokes and Preston 2016). As a result, estimates of the risks associated with obesity are biased downwards, sometimes even creating the illusion of a survival advantage for overweight or obese individuals (Stokes and Preston 2016). One solution is to calculate lifetime maximum BMI based on highest-ever weight (Stokes and Preston 2016; Stokes 2014; Stokes and Preston 2016). Maximum BMI is a more robust predictor of mortality than BMI at survey (Mehta et al. 2014; Stokes and Preston 2016).

1.3 Study aim

This study investigates the contribution of adiposity to educational mortality differentials in the United States, using several measures of adiposity. Previous research finding no contribution of obesity to educational mortality differences relies on BMI at time of survey, a measure which may underestimate the risks of obesity (Stokes and Preston 2016; Stokes and Preston 2016). Although maximum BMI has already been applied to examine racial differences in mortality (Elo et al. 2016), maximum BMI has not before been used to examine educational differences in mortality. Accurately quantifying adiposity's contribution to educational mortality differentials is crucial for reducing mortality disparities in a context of increasing obesity prevalence.

Although this analysis uses data from the United States, given the country's vanguard position in a global trend of rising obesity prevalence, the findings of this analysis are likely generalizable to other high-income countries with comparable inequalities in mortality and obesity by educational attainment. Existing research indicates that many European countries may fit this description (Devaux and Sassi 2013; Mackenbach et al. 2008; Robertson et al. 2007).

2. Data and methods

2.1 Data source and sample

This analysis uses data from the National Health and Nutrition Examination Survey (NHANES), an annual cross-sectional health survey administered by the National Center for Health Statistics (NCHS). I combine data from NHANES III (1988-1994) and NHANES Continuous (1999-2010) waves, weighted to be nationally representative of the non-institutionalized US population. In addition to participating in detailed in-person interviews, adult respondents visit mobile examination centers for physical examinations. The participation rates for the years included in the sample range from 75% to 80% (Centers for Disease Control 2015). Each wave has been linked to the National Death Index through December 2011, allowing for mortality follow-up. More detailed information on survey design and sampling procedures are available elsewhere (Centers for Disease Control and Prevention 1996; Johnson et al. 2013).

I restrict the study population for the main analysis to respondents aged 40 to 74 at time of survey who were physically examined, not pregnant at time of survey and not missing information on measured height, measured weight and self-reported maximum weight. I exclude respondents missing information on educational attainment (n=58) and smoking (n=8). Since the aim of this analysis is to examine the contribution of obesity to mortality differences, I exclude respondents who have always been underweight (maximum BMI<18.5) (n=19). I also exclude respondents with maximum BMI values of 60 or greater (equivalent to being 5’8 tall and weighing 400 pounds) (n=90). Respondents are censored upon reaching age 85 during mortality follow-up. The final sample combines respondents from each wave and consists of 22,995 respondents experiencing 239,789 person-years of follow-up and 3,883 deaths from all causes. The mean length of follow-up is 9.5 years.

2.2 Variable design

Outcome variable

The dependent variable is all-cause mortality as registered in the National Death Index between participation in the survey and December 31st, 2011.

Education

Earlier NHANES waves (1988-1994) measured education as years of completed schooling, ranging from 0 to 17 years. Later waves (1999-2010) collected this information using a five-level categorical variable (<9th grade, <high school, high school degree/GED, some college/associate’s degree, bachelor’s degree or more). For descriptive purposes, I convert data from earlier waves into these five categories, using years of completed schooling. However, a continuous measure of education is preferable for the regression analyses as it better captures a nuanced educational gradient.

To convert categorical data from later waves into a continuous measure, I use educational attainment data from the Current Population Survey (CPS), a nationally-representative monthly survey administered by the US Census Bureau. The CPS measures educational attainment using 15 levels, compared to just 5 in NHANES. I calculate average years of schooling for each of the five NHANES levels, weighted by the distribution of educational attainment in the CPS for the same calendar year. I repeat this for each 5 year age-interval, so that a respondent's years of completed schooling depend on the survey year, the respondent's age, and the respondent's broader category of educational attainment. A detailed description of the variable's construction is given in the Appendix.

Measures of Adiposity

In the main analysis, I examine two measures of BMI: BMI at time of survey and lifetime maximum BMI. BMI, calculated as weight in kilograms over height in meters squared, is a commonly used estimator of adiposity. Values between 18.5 and 25 are considered healthy, values between 25 and 30 are considered overweight, and values of 30 or higher are considered obese. I use the terms adiposity and obesity interchangeably throughout this study.

I construct a continuous measure for BMI at survey using height and weight, both measured at a mobile examination center at the time of survey. To construct a variable for maximum BMI, I use measured height and self-reported highest-ever weight. Although respondents in NHANES tend to under-report their weight, Preston et al. (2015) show that bias from weight misreporting in estimates of the mortality consequences of obesity are greatly reduced if using a continuous measure of BMI.

In later sensitivity analyses, I examine two additional estimates of adiposity. The first is BMI at age 25, which is constructed using height measured at time of survey and self-reported weight at age 25. The second is waist circumference in centimeters, measured at time of survey.

Other covariates

Age, sex and race/ethnicity are correlated with BMI (Elo et al. 2016; Heymsfield et al. 2016; Reynolds et al. 2005; Zhang and Wang 2004) and included as additional covariates. I operationalize age as a time-varying variable. I also include a categorical variable for smoking history, capturing never smokers, former smokers and current smokers. Because smokers, especially life-long smokers, have a higher risk of death and are more likely to have a healthy BMI (Audrain-McGovern and Benowitz 2011; Stokes and Preston 2016), cigarette use can obscure the relationship between obesity and mortality (Stokes and Preston 2016). Threats of confounding are particularly serious in studies of educational attainment and mortality, given the inverse relationship between smoking and education (Centers for Disease Control and Prevention 2015).

2.3 Analytic strategy

I model the relationship between education and mortality using discrete time logistic regressions. The full model includes variables for age, age squared, sex, race/ethnicity, education, smoking, and one of two adiposity measures (either BMI at survey or maximum BMI). Using the model performance criteria Akaike information criterion (AIC) and Bayesion information criterion (BIC), I compare the full model using survey BMI to the full model using maximum BMI to determine which estimate of adiposity produces the best performing model.

Next, I estimate the percentage of the education-mortality relationship that is mediated by educational differences in adiposity. In a logistic model, a coefficient can change across nested models both because an added variable (in this case, the variable for adiposity) mediates the relationship between the independent variable of interest (education) and the dependent variable (mortality) and because the underlying scale of the model has shifted (Karlson et al. 2012). It is not sufficient, therefore, to estimate the percentage of the education-mortality relationship that is associated with obesity by examining the change in the education coefficient across nested models before and after controlling for adiposity. If done this way, it is unclear how much the coefficient for education has changed due to: 1) obesity mediating the association between education and mortality; and 2) the shift in the scale caused by the introduction of a new variable. Furthermore, failure to correct for rescaling often underestimates the mediating role of a variable, *z* (obesity), in a relationship between *x* and *y* (education and mortality), "increasing the likelihood of our concluding, incorrectly, that changing *z* would have little or no impact on the *x*-*y* relationship (Karlson et al. 2012)."

To address this issue, I use a method proposed by Karlson, Holm and Breen (2012), using the *khb* command (2012) in Stata version 14 (StataCorp 2015). The underlying discrete time logistic regressions model both smoking and adiposity as mediators in the relationship between education and mortality. The models additionally include demographic controls for age, age squared, sex and race/ethnicity. In a sensitivity analysis, I repeat the *khb* decomposition examining the contribution of two additional estimates of adiposity to educational mortality differences: waist circumference measured at survey time and BMI at age 25.

Finally, I repeat the above *khb* procedure restricting the sample by sex and non-smoking status using only the best performing estimate of adiposity. Since smoking increases mortality risks and is inversely related to obesity (Audrain-McGovern and Benowitz 2011; Stokes and Preston 2016), measurement error in smoking status, such as the inability to account for smoking duration and intensity, may bias the relationship between obesity and mortality (Renehan et al.

2012; Stokes and Preston 2016). Although less generalizable to the overall population, results for never-smokers present a less biased picture of obesity's contribution to mortality differences.

3. Results

3.1 Descriptive statistics and age-standardized mortality rates

Table 1 presents characteristics of the sample by educational attainment, weighted to be nationally-representative of the non-institutionalized population. The majority (61%) of respondents have at most a high school degree, and just over one-fifth (21%) of respondents have some college experience or an associate's degree, but no bachelor's degree. Respondents with bachelor's degrees are more likely than those without four-year degrees to be younger, non-Hispanic white never-smokers. At survey, one-quarter (25%) of college-educated respondents were obese, compared to one-third (34%) of those with some college but no bachelor's degree. Roughly one-third (35%) of the former group reported having ever been obese, as measured by maximum BMI, compared to nearly half (48%) of the latter group. The relationship between education and having ever been obese is somewhat more linear than between education and being obese at time of survey, suggesting that BMI at survey may hide important heterogeneity. This may be partly due to the educational patterning of current smoking, as smoking is negatively correlated with current weight (Centers for Disease Control and Prevention 2015). Among those with more than a 9^{th} grade education, but less than a high school degree, 37% reported being current smokers, compared to 10% of those with at least 4 years of college.

Age-standardized mortality rates decrease with education. As reported in Table 1, those without a high school degree are more than twice as likely as college-educated respondents to die during follow-up (12.06 deaths vs. 5.30 deaths per 1,000 for females and 18.05 vs. 7.56 deaths per 1,000 for males, respectively). The trend is less pronounced when comparing those with less than 9 years of education to those with between 9 and 12 years of education: this effect is likely driven by the well-documented Hispanic health paradox (Markides and Coreil 1986). Among those with less than a 9th grade education, 28% are foreign-born Hispanics, compared to 7% of those with between 9 and 12 years of schooling (available upon request). Figure 1, which plots education and mortality rates among non-Hispanic whites, the largest racial/ethnic group, indicates a linear relationship across five categories of education. Non-Hispanic whites with less than a ninth grade education experienced roughly three times the mortality rates of non-Hispanic whites with at least a bachelor's degree during follow-up. This pattern supports the use of a continuous measure for education.

Table 2 presents characteristics of the sample for never and current smokers by sex. Current smokers have fewer years of schooling than never smokers (a difference of 0.8 years for females and 1.8 years for males) and are also less likely to be or have ever been obese. Differences in BMI by smoking status are lessened if using maximum BMI. Although never-smoking females were 27% more likely than currently smoking females to be obese at time of survey, they were only 11% more likely to have ever been obese. For males, these figures were 38% and 8%, respectively. Despite current smokers' healthier weight, current smokers experience more than twice the mortality rates of never smokers, illustrating smoking's confounding role in the relationship between obesity and mortality. The age-standardized mortality rate for currently smoking males is 23.57 annual deaths per 1,000, more than 14 deaths higher than the rate of 9.14 deaths per 1,000 among never-smoking men. For women, these rates are 17.64 and 7.20 deaths per 1,000, respectively.

3.2 Model performance

Table 3 presents odds ratios of dying from all-cause mortality. Model 1 estimates the baseline relationship between education and mortality, controlling for age, sex, race/ethnicity, and smoking, while Models 2 and 3 each add a different estimate of adiposity. Although previous research has shown the inclusion of a quadratic term for obesity estimates to improve model performance (Kivimaki et al. 2008), this was only the case for the model using survey BMI. I therefore only include a quadratic term for the model including survey BMI. I did not find evidence of significant interactions between obesity+sex, obesity+education, obesity+age, education+sex or education+smoking in either model.

Model performance criteria AIC and BIC are presented in Table 1 and graphically in Figure 2. Model 3, which uses maximum BMI, performs better than Models 1 and 2 (AIC values of 36,412 versus 36,529 and 36,468, respectively; BIC values of 36,527 versus 36,633 and 36,593, respectively). This is consistent with previous research that used these model selection criteria to compare maximum BMI to BMI at survey (Stokes and Preston 2016).

3.3 Karlson, Holm & Breen decompositions

In Model 1, each additional year of education is associated with a 7.1% reduction in the annual odds of dying. If we account for the fact that less educated people are more likely to be obese at survey in Model 2, the survival benefits of education decline somewhat: in Model 2, each additional year of education is associated with a 6.9% reduction in the odds of dying. In Model 3, using maximum BMI instead of survey BMI, each additional year of education is associated with 6.4% reduction in the annual odds of dying. However, since the coefficient for education may change across Model 1 and the models controlling for adiposity both because of the mediating effect of BMI and because of a shift in the underlying scale of the model, it is not sufficient to calculate the percentage change in the education coefficient across models. I account for rescaling by using Karlson, Holm & Breen (2012) decompositions.

Results of the decompositions, given in Figure 3, indicate that the percentage of educational mortality differences associated with adiposity are sensitive to how adiposity is measured. When estimated using maximum BMI, the better performing variable, adiposity is associated with a 9.2% reduction in overall educational mortality differences, compared to a 2.2% reduction when using survey BMI, as previous studies have done. Figure 3 also includes results from a sensitivity analysis examining the explanatory power of two additional measures of body fat: waist circumference at survey and BMI at age 25. Although these measures are associated with a somewhat larger proportion of mortality differences than BMI at survey (2.9% and 4.1%, respectively), neither account for more of the differential, nor produce better-performing models, than does maximum BMI.

Figure 4 presents results by sex both for the entire sample and for never-smokers, using maximum BMI as a proxy for adiposity. In the overall population, differences in maximum BMI are associated with a larger share of educational mortality differences among women than men (12.4% vs 6.9%), likely due in part to the higher prevalence of smoking among men and the stronger education-obesity gradient among women (Yu 2012). Among never-smokers, adiposity is an even more powerful mediator in the relationship between education and mortality: 15.8% of educational differences in mortality among never-smokers can be accounted for by differences in maximum BMI. The results are somewhat similar for never-smoking women (16.8%) and men (14.1%).

4. Discussion and conclusion

Despite large gains in life expectancy in the United States and other high income countries over the past century, substantial differences in mortality conditions persist across subpopulations. One of many stratifying dimensions is educational attainment: people with fewer years of schooling live fewer years, and spend fewer of these years healthy (see e.g., Elo 2009; Hayward et al. 2015; Laditka and Laditka 2016; Mackenbach et al. 2008; Mackenbach et al. 2015). Using nationally-representative data, I find that educational differences in adiposity contribute to this disparity in the United States, though the size of adiposity's contribution is sensitive to how adiposity is measured.

The majority of prior work, finding little or no association between obesity and educational differences in mortality, relies exclusively on a single, cross-sectional observation of BMI at time of survey. This approach can underestimate the risks of obesity since reverse causation due to illness biases the mortality risks of obesity downward (Stokes and Preston 2016; Stokes and Preston 2016). The likelihood of reverse causation is especially great among less educated people, who are more likely to smoke and to contract illnesses that induce weight loss. Lifetime maximum BMI may be a more reliable estimate of adiposity. No research has yet explored differences in maximum BMI by educational attainment, nor quantified the contribution of these differences to existing mortality disparities.

The main analysis compared models of mortality using BMI at survey and lifetime maximum BMI, finding that, based on model performance criteria AIC and BIC, models with maximum BMI best explained the observed data. This is consistent with previous research documenting the strengths of maximum BMI as a variable to estimate obesity (Preston et al. 2015; Stokes and Preston 2016). Consistent with prior research, I find that adiposity accounts for little of educational mortality differences (2.2%) when estimating obesity using BMI at survey. However, when using maximum BMI, obesity is associated with 9.2% of educational mortality differences, five times more than survey BMI. Although this analysis used US data, it is likely that these findings are applicable to other high income countries with comparable socio-economic disparities in obesity and mortality.

A limitation of this analysis is that maximum weight in NHANES is self-reported, and therefore likely under-reported. If weight under-reporting increases with weight, which is conceivable, the results in this analysis may be conservative: less-educated respondents are more likely to have higher BMIs, and therefore possibly also more likely to underreport their weight.

Although this study quantifies the extent to which differences in adiposity contribute to educational mortality disparities, it cannot provide insight into the more upstream factors shaping differential obesity prevalence by educational attainment in the first place. This is an important avenue for future research. Additionally, future research should also investigate whether the pathways between maximum BMI and mortality are social or biological, or both. A social pathway could include heavier respondents seeking medical care less often because of their weight. It is also possible that, since peak weight indicates an extreme in an individual’s weight history, maximum BMI captures social aspects associated with weight fluctuations, such as stressful life events. If, however, maximum BMI influences mortality mainly through biological mechanisms, the finding that having ever been obese is associated with elevated mortality risks indicates the importance of examining duration of, and age at, peak weight.

The superior performance of maximum BMI highlights the need for health surveys to collect data on maximum weight. Without declines in obesity prevalence, the power of obesity in shaping the education-mortality relationship is likely to grow. Although the sharp decline in smoking in recent years (Centers for Disease Control and Prevention 2015) is a positive development for health outcomes, it also indicates that obesity may take on a larger role in driving mortality differentials. Among the growing number of never-smokers, maximum BMI is associated with nearly one-fifth (17%) of the educational mortality differential, underscoring the urgency of levelling differences in obesity prevalence by educational attainment.

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Table 1. Sample characteristics by educational attainment[a], ages 40-74

Characteristic	<9th grade	<High school	High school/ GED	Some college or Associate's degree	Bachelor's degree or more	Total
Mortality rate (per 1,000)[b]						
Female	12.06	11.78	9.29	7.82	5.30	8.94
Male	18.05	17.41	14.75	12.58	7.56	13.13
Obesity						
Currently obese[c] (%)	34.2 (31.8 to 36.4)	37.1 (34.7 to 39.6)	34.2 (32.2 to 36.1)	34.4 (32.6 to 36.3)	24.6 (23.0 to 26.3)	32.2 (31.1 to 33.3)
Ever obese[c] (%)	50.9 (48.8 to 53.0)	52.4 (50.5 to 54.4)	48.8 (46.7 to 50.9)	48.1 (46.0 to 50.3)	35.2 (33.1 to 37.3)	45.9 (44.6 to 47.1)
BMI[d] survey (mean)	28.5 (28.1 to 28.8)	28.8 (28.6 to 29.1)	28.6 (28.4 to 28.8)	28.6 (28.3 to 28.9)	27.3 (27.0 to 27.5)	28.3 (28.1 to 28.4)
BMI[d] maximum (mean)	31.1 (30.7 to 31.5)	31.4 (31.1 to 31.7)	30.8 (30.6 to 31.1)	30.7 (30.4 to 31.0)	29.1 (28.8 to 29.3)	30.5 (30.3 to 30.6)
Age at survey (mean)	58.7 (58.1 to 59.3)	56.1 (55.6 to 56.6)	54.9 (54.4 to 55.4)	53.3 (53.0 to 53.7)	52.9 (52.5 to 53.3)	54.5 (54.2 to 54.8)
Age at follow up (mean)	70.1 (69.4 to 70.8)	67.1 (66.3 to 67.8)	66.5 (65.9 to 67.1)	63.2 (62.7 to 63.7)	63.8 (63.2 to 64.4)	65.5 (65.0 to 65.9)
Male (%)	50.4 (48.3 to 52.5)	47.7 (45.7 to 49.7)	44.2 (42.8 to 45.6)	46.1 (43.9 to 48.3)	54.4 (52.7 to 56.0)	48.3 (47.5 to 49.0)
Race/ethnicity (%)						
Non-Hispanic white	47.6 (42.1 to 53.1)	67.0 (63.2 to 70.7)	81.2 (79.1 to 83.2)	79.5 (77.5 to 81.5)	85.6 (83.7 to 87.6)	77.0 (75.0 to 78.9)
Non-Hispanic black	12.1 (10.1 to 14.1)	18.8 (16.4 to 21.2)	10.0 (8.8 to 11.2)	9.9 (8.7 to 11.2)	5.5 (4.7 to 6.3)	10.2 (9.2 to 11.1)
Hispanic	33.7 (28.6 to 38.9)	11.1 (9.0 to 12.9)	5.9 (4.9 to 6.9)	6.6 (5.6 to 7.7)	3.5 (2.8 to 4.3)	8.7 (7.5 to 9.9)
Other	6.6 (4.6 to 8.6)	3.3 (2.0 to 4.5)	3.0 (2.2 to 3.7)	3.9 (3.2 to 4.7)	5.3 (3.8 to 6.9)	4.2 (3.5 to 4.9)
Smoking status (%)						
Never smoker	43.1 (40.4 to 45.9)	33.0 (30.5 to 35.6)	40.8 (39.0 to 42.6)	44.2 (42.3 to 46.0)	55.1 (53.0 to 57.3)	44.5 (43.2 to 45.7)
Former smoker	30.5 (28.6 to 32.4)	30.2 (28.0 to 32.4)	31.1 (29.6 to 32.7)	33.9 (31.9 to 35.9)	34.0 (32.0 to 36.1)	32.3 (31.3 to 33.4)
Current smoker	26.4 (24.2 to 28.5)	36.8 (34.4 to 39.1)	28.0 (26.6 to 29.5)	22.0 (20.2 to 23.7)	10.8 (9.4 to 12.2)	23.2 (22.2 to 24.2)
N	4,390	3,715	5,851	4,928	4,111	22,995
Deaths	1,246	781	993	534	329	3,883
Person Years	49,601	38,304	64,633	45,965	41,286	239,789

Source: NHANES (1988-1994) and (1999-2010).
Percentages and means shown, with 95% CIs in parentheses. Results reflect sample weighting except N, deaths, and person years.
a. Categorical variable for education used for descriptive purposes only. Linear variable used in later regression analyses.
b. Mortality rates include mortality until age 85. Rates are age-adjusted using the age distribution in the 2000 Census.
c. Currently obese estimated as BMI at survey greater than 30. Ever obese estimated as maximum BMI greater than 30.
d. BMI: body mass index.

Table 2. Sample characteristics by sex and smoking status, ages 40-74

Characteristic	Female		Male	
	Never-smoker	Current smoker	Never-smoker	Current smoker
Adjusted mortality rate (per 1,000)[a]	7.20	17.64	9.14	23.57
Years of education (mean)	12.8 (12.7 to 13.0)	12.0 (11.9 to 12.2)	13.7 (13.6 to 13.9)	11.9 (11.7 to 12.0)
Obesity measures				
Currently obese[b] (%)	35.8 (34.1 to 37.5)	28.3 (26.4 to 30.2)	32.2 (29.6 to 34.9)	23.3 (21.0 to 25.4)
Ever obese[b] (%)	45.0 (43.3 to 46.8)	40.7 (38.5 to 42.8)	46.9 (44.3 to 49.5)	43.3 (40.9 to 45.8)
BMI[c] survey (mean)	28.6 (28.4 to 28.8)	27.1 (26.8 to 27.4)	28.7 (28.4 to 29.0)	26.9 (26.7 to 27.2)
BMI[c] maximum (mean)	30.4 (30.2 to 30.7)	29.8 (29.4 to 30.2)	30.7 (30.4 to 31.0)	29.9 (29.7 to 30.2)
Age at survey (mean)	54.8 (54.3 to 55.2)	52.8 (52.3 to 53.3)	52.9 (52.4 to 53.3)	52.1 (51.7 to 52.5)
Age at follow up (mean)	65.9 (65.3 to 66.4)	63.9 (63.2 to 64.6)	62.9 (62.3 to 63.5)	63.1 (62.5 to 63.6)
Race/ethnicity (%)				
Non-Hispanic white	72.0 (69.3 to 74.6)	76.5 (73.6 to 79.4)	76.7 (74.4 to 79.0)	72.6 (69.8 to 75.3)
Non-Hispanic black	11.2 (9.9 to 12.5)	13.3 (11.6 to 15.0)	9.1 (8.1 to 10.1)	14.5 (12.9 to 16.1)
Hispanic	10.8 (9.3 to 12.4)	6.8 (5.3 to 8.4)	9.4 (8.1 to 10.7)	8.5 (6.7 to 10.4)
Other	5.6 (4.6 to 7.3)	3.4 (2.2 to 4.5)	4.8 (3.5 to 6.1)	4.4 (3.2 to 5.6)
N	6,616	2,284	3,846	3,116
Deaths	737	480	435	833
Person Years	71,627	24,278	37,585	32,123

Source: NHANES (1988-1994) and (1999-2010).

Percentages and means shown, with 95% CIs in parentheses. Results reflect sample weighting except N, deaths, and person years.

a. Mortality rates include mortality until age 85. Rates are age-adjusted using the age distribution in the 2000 Census.

b. Currently obese estimated as BMI at survey greater than 30. Ever obese estimated as maximum BMI greater than 30.

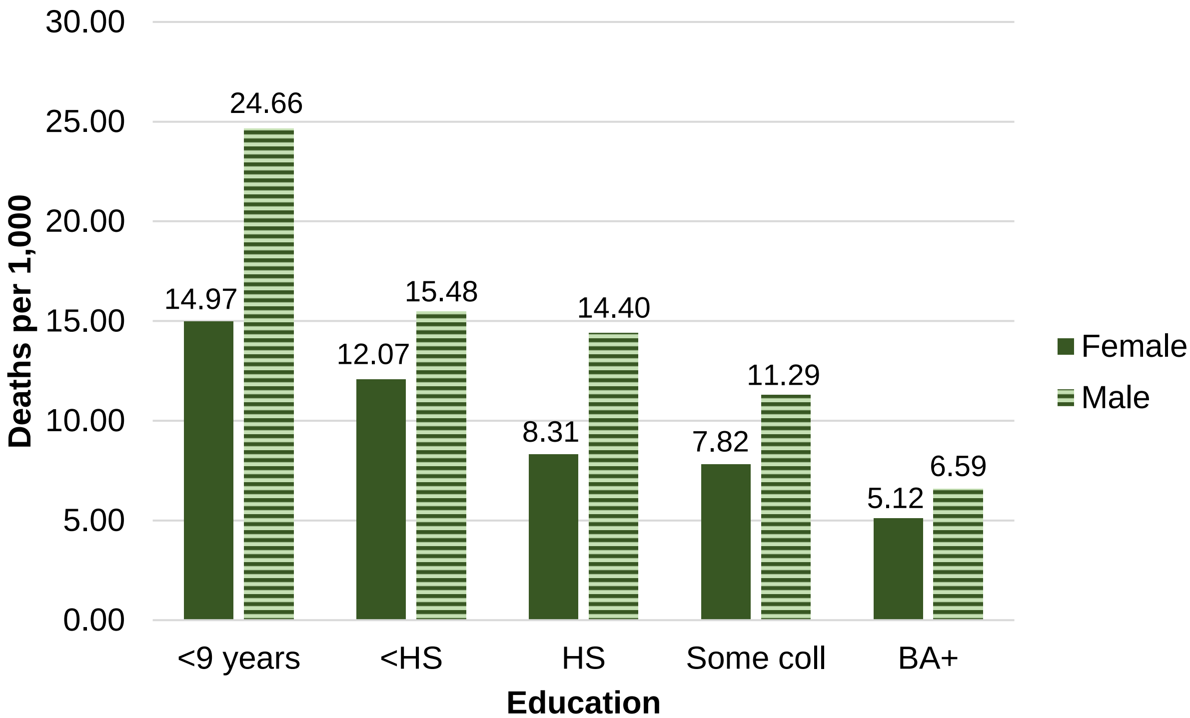
c. BMI: body mass index

Table 3. Odds ratios of dying from all-cause mortality during mortality follow-up, discrete time logistic regressions

Characteristics	**Model 1: Baseline**	**Model 2: Survey BMI**	**Model 3: Maximum BMI**
Education (years)	0.929*** [0.913 to 0.945]	0.931*** 0.915 to 0.947]	0.936*** [0.920 to 0.952]
Age	1.019 [0.955 to 1.086]	1.017 [0.953 to 1.084]	1.011 [0.948 to 1.078]
Age squared	1.001* [1.0001 to 1.001]	1.001* [1.0001 to 1.001]	1.001* [1.0001 to 1.001]
Sex (ref: female)	1.305*** [1.197 to 1.424]	1.368*** [1.245 to 1.503]	1.310*** [1.197 to 1.433]
Race (ref: NH white)			
NH black	1.329*** [1.198 to 1.475]	1.271*** [1.144 to 1.413]	1.250*** [1.124 to 1.390]
Hispanic	0.767** [0.648 to 0.909]	0.778** [0.659 to 0.919]	0.778** [0.664 to 0.913]
Other	1.023 [0.739 to 1.417]	1.044 [0.751 to 1.452]	1.120 [0.797 to 1.574]
Smoker (ref: never)			
Former	1.508*** [1.343 to 1.694]	1.514*** [1.352 to 1.696]	1.502*** [1.339 to 1.684]
Current	2.812*** [2.469 to 3.203]	2.896*** [2.537 to 3.305]	3.017*** [2.647 to 3.438]
Adiposity			
BMI (survey)		0.896*** [0.861 to 0.933]	
BMI (survey) squared		1.002*** [1.001 to 1.003]	
BMI (maximum)			1.042*** [1.034 to 1.049]
Constant	0.000 [0.000 to 0.004]	0.002 [0.000 to 0.016]	0.000 [0.000 to 0.001]
AIC	36,529.05	36,467.52	36,412.12
BIC	36,633.35	36,592.68	36,526.86
N		22,995	
Deaths		3,883	
Person years		250,242	

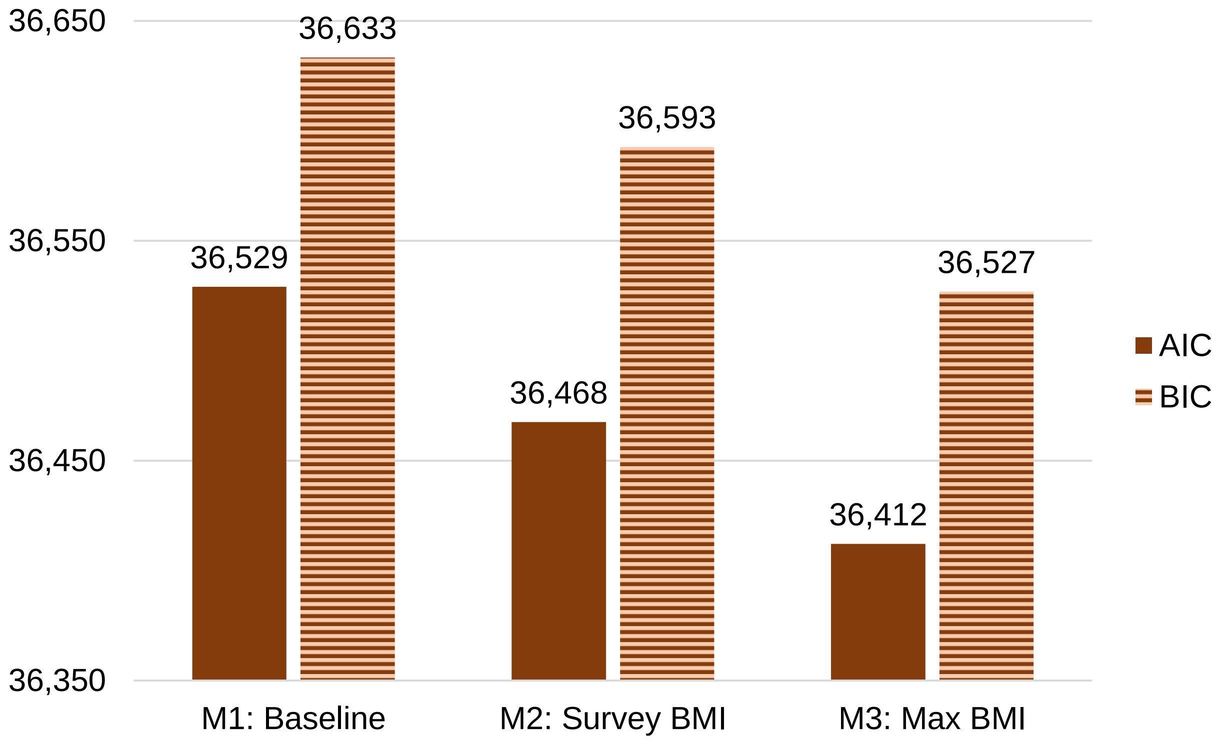
Source: NHANES (1988-1994) and (1999-2010). Results reflect sample weighting except AIC, BIC, N, deaths, and person years. Exponentiated coefficients; 95% confidence intervals in brackets.
Sample restricted to individuals aged 40-74 at baseline with maximum BMI between 18.5 and 60 not missing data on key variables. Individuals censored upon reaching age 85 during follow-up.

Figure 1. Age-standardized annual mortality rates during follow-up for non-Hispanic whites



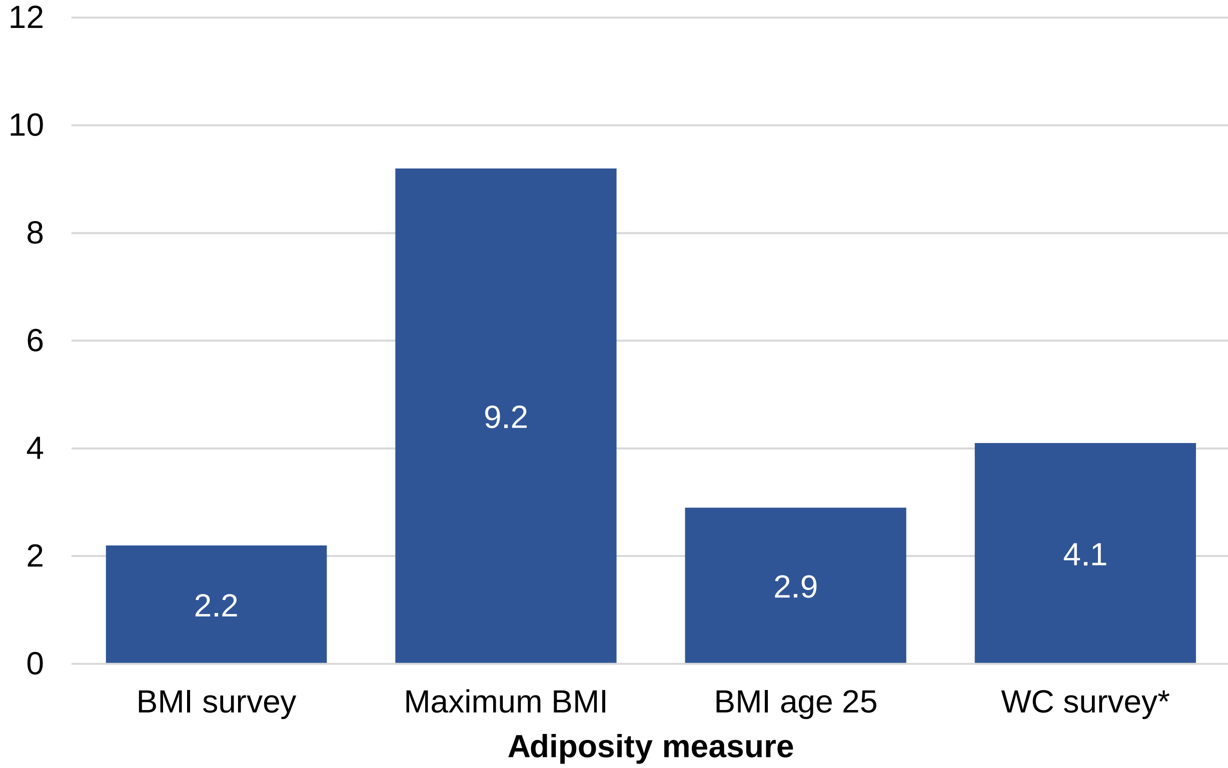
Source: NHANES (1988-1994) and (1999-2010).
Results reflect sample weighting.
Sample restricted to individuals aged 40-74 at baseline with maximum BMI between 18.5 and 60 not missing data on key variables. Individuals censored upon reaching age 85 during follow-up.
Data for non-Hispanic whites shown for expositional purposes only. Main analysis not limited to non-Hispanic whites. Educational attainment operationalized as a categorical variable for descriptive analyses only. Regression analyses employ a continuous measure of education.

Figure 2. Model performance of discrete time logistic regressions modeling mortality during follow-up period by adiposity measure



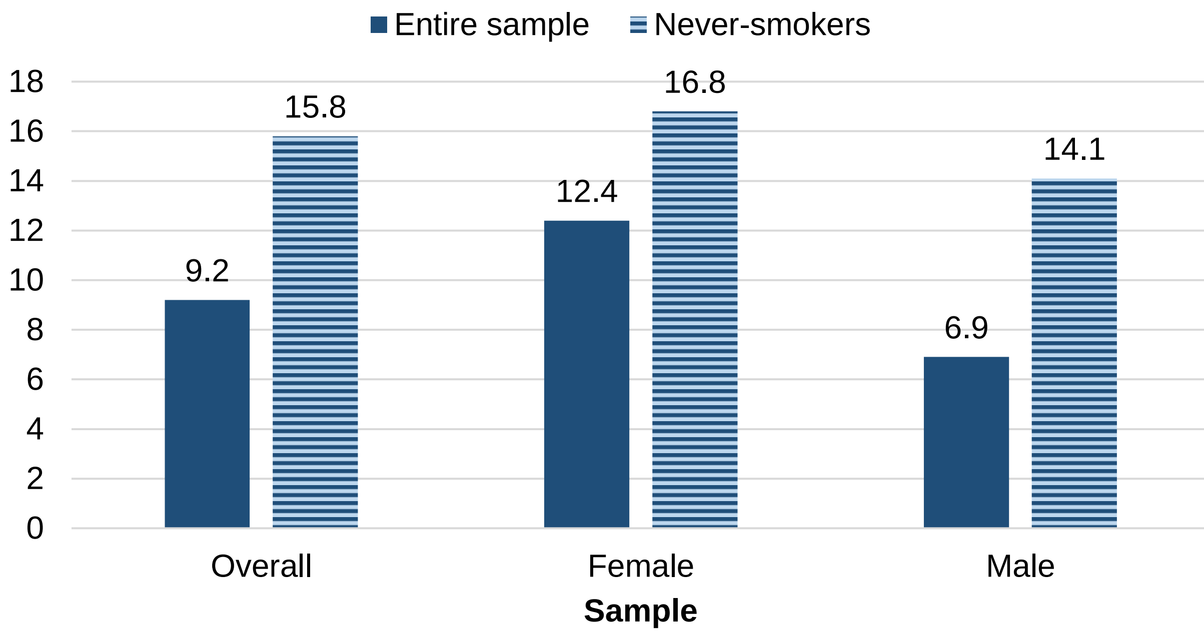
Source: NHANES (1988-1994) and (1999-2010)
All models control for age, age-squared, sex, race/ethnicity, smoking status, and education. Model 2 adds BMI at time of survey to the baseline model. Model 3 adds maximum BMI to the baseline model. Although previous research has shown the inclusion of a quadratic term for obesity estimates to improve model performance, this was only the case for the model using survey BMI. I therefore only include a quadratic term for the model including survey BMI.
AIC: Akaike information criterion; BIC: Bayesian information criterion

Figure 3. Percentage of educational mortality differential associated with adiposity, by adiposity measure



Source: NHANES (1988-1994) and (1999-2010)
Results obtained using Karlson to Holm & Breen (2012) decompositions of discrete time logistic regressions. All models include adiposity and smoking status as mediators of the relationship between education and mortality. All models include additional covariates for age, age-square, sex, race/ethnicity, smoking status, and education. Although previous research has shown the inclusion of a quadratic term for obesity estimates to improve model performance, this was only the case for the models using survey BMI and waist circumference at survey. I therefore only include a quadratic term for these two models.
*WC survey: waist circumference at survey time.

Figure 4. Percentage of educational mortality differential associated with maximum BMI, by sex and smoking status



Source: NHANES (1988-1994) and (1999-2010)
Results obtained using Karlson, Holm & Breen (2012) decompositions of discrete time logistic regressions. All models include adiposity and smoking status (if applicable) as mediators of the relationship between education and mortality. All models include additional covariates for age, age-squared, sex (if applicable), race/ethnicity, smoking status (if applicable), and education.

Appendix

Creating a continuous measure of education for NHANES Continuous waves 1999-2010

NHANES Continuous waves 1999-2010 measured educational attainment in five categories (<9th grade, <high school, high school/GED, some college/associate's degree, bachelor's degree or more). I use educational attainment data from the annual Current Population Survey (CPS) to compute the average years of schooling within each broader NHANES category by age and year. The CPS includes 15 categories of educational attainment, to each of which I assign a number of years, shown in Table 1S. Table 1S excludes those with a high school diploma, which I assign a value of 12 years.

For educational attainment beyond a high school degree, CPS does not indicate an equivalent number of years of education. I therefore assume that an associate's degree is equivalent to 14 years of education, a bachelor's degree to 16 years, a master's degree to 18 years, a professional degree to 19 years and a PhD to 21 years of education. To estimate the number of years for those with some college experience, but no degree, I use the average number of years from NHANES III (in which education is measured in years of schooling) among those with between 12 and 16 years of education, excluding those with 14 years of education (assuming 14 years of education indicates an associate's degree). Results are not sensitive to small changes in parameters (such as assigning a value of 25 years to a PhD, instead of 21).

For each broader NHANES category, I determine the distribution of individuals within the narrower CPS categories. For the <9th grade category in NHANES, for example, I examine the distribution of individuals within the four CPS categories with less than 9 years of education. I use the number assigned to each CPS category as outlined above to calculate an average number of years of schooling for each NHANES category, weighted by the distribution within that category in the CPS. I do this for each five-year age interval and annual CPS wave. An example for 60-64 year-olds in 2010 is shown in Table 1S below. Since NHANES waves are two-year waves, I average the CPS averages for the two years of the NHANES wave.

Table 2S gives average years of schooling for NHANES III (collected as a continuous measure) and NHANES Continuous (converted into a continuous measure). The estimates for the NHANES Continuous waves are consistent with the values given by respondents in NHANES III, with the exception of the estimates for bachelor's degree or higher. Because 17 was the maximum years of education NHANES III respondents could indicate (compared to the estimated 21 years for PhD recipients in CPS data), the average value for those with a bachelor's degree or higher in NHANES III is half a year lower than in later waves (16.48 vs. 17.00). Sensitivity analyses indicate that findings are not sensitive to this small difference. Some college, but no associate's degree, is assigned a value of 13.63 years. This is based on the mean years of schooling indicated by those in NHANES III who indicated more than 12 years and less than 16 years of schooling, but not 14 (interpreted as an associate's degree).

The standard deviations of years of educational attainment are small for NHANES Continuous waves, since the only variation is due to differences in survey year or respondent's age. However, this is not likely to bias estimates upwards. The calculation process described above introduces measurement error for each observation, biasing coefficients downwards.

Appendix Table 1. Computation of average years of schooling for 50-54 year-olds in NHANES 2009-2010[a]

Educational attainment	# years	CPS distribution of educational attainment (%)	Weighted average (years)
	<9th grade		5.32
None	0	6.9	
Grades 1-4	2.5	18.9	
Grades 5-6	5.5	36.0	
Grades 7-8	7.5	38.2	
	<High school		10.31
Grade 9	9	19.8	
Grade 10	10	29.1	
Grade 11	11	51.1	
	Some college or associate's degree		13.77
Some college	13.63	62.3	
Associate's (o)[b]	14	16.5	
Associate's (a)[c]	14	21.2	
	Bachelor's degree or more		16.93
Bachelor's	16	63.8	
Master's	18	25.9	
Professional	19	5.1	
PhD	21	5.2	

a. This example uses 2010 CPS data. These steps are then repeated with 2009 CPS data and the values from 2009 and 2010 averaged to obtain estimates for the two year period.
b. Occupational associate's degree
c. Academic associate's degree

Appendix Table 2. Mean years of schooling for selected NHANES educational attainment categories, based on CPS data

	Wave						
Education	1988-1994[a]	1999-2000[b]	2001-2002[b]	2003-2004[b]	2005-2006[b]	2007-2008[b]	2009-2010[b]
<9th grade	5.31	5.38	5.42	5.54	5.57	5.65	5.69
<High school	10.04	10.21	10.22	10.22	10.23	10.24	10.27
Some college	13.57	13.74	13.75	13.75	13.76	13.75	13.76
Bachelor's or more	16.48	16.99	17.00	17.00	17.01	17.02	17.03

a. 1998-1994 data is from NHANES III, which collected years of schooling. Data in this column was observed in the sample and is not calculated from CPS data.
b. Constructed using averaged CPS data from those years according to process described above.