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Dynamics of Health Behaviors and Socioeconomic Differences in Mortality in the United States

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Abstract

Background—To measure the explanatory role of behavioral factors to educational and income disparities in mortality among U.S. adults (ages 25+).

Methods—Data were from 4 waves of the American Changing Lives Study (N=3,617). There were 1,832 deaths between 1986 and 2011. Smoking, physical activity, alcohol, and BMI were examined.

Results—Those with 0–11 years of schooling had an 88% (95% CI: 48%, 139%) increased risk of dying compared to those with 16+ years of schooling. Behavioral factors explained 41% (95% CI: 26%, 55%) and 50% (95% CI: 30%, 70%) of this excess in models that treated behavioral factors as fixed (single point in time) and time-varying (repeated), respectively. The lowest income group (bottom 20th percentile) had a 209% (95% CI: 172%, 256%) increased risk of dying relative to the highest income group (top 40th percentile). Behavioral factors explained 24% (fixed, 95% CI: 13%, 35%) and 39% (repeated, 95% CI: 22%, 56%) of this difference. Analyses of deaths by causes indicated that behavioral factors were more consequential to disparities in cardiovascular mortality, explaining up to 83% of educational differences, compared to cancer and other death causes.

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Contributorship Statement: Neil Mehta had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. All authors conceived and designed the study. Neil Mehta drafted the initial manuscript and all authors provided critical revisions of the manuscript for important intellectual content. Michael Elliott provided additional statistical and analytical guidance. James House has directed the ACL study from its inception.

Conclusion—Behavioral factors are one of a number of factors which explain socioeconomic mortality disparities, but their estimated explanatory role depends on a number of parameters including the SES measure examined, the cause of death, and age. In this nationally representative sample, findings based on repeated measures did not warrant a reevaluation of earlier estimates.

Keywords

Socioeconomic disparities; health behaviors; education; income; mortality

Introduction

Socioeconomic status (SES) differences in mortality remain strikingly persistent despite considerable changes over time in the factors that may give rise to these differences and changes in the distribution of the causes of death (e.g., declining cardiovascular disease mortality).[1–4] A large body of literature has sought to measure the relative contributions of various factors—behaviors, psychosocial mechanisms, healthcare—to the production of these mortality differentials.[5–13]

The specific contribution of modifiable behaviors—cigarette smoking, physical activity, diet, alcohol use—to SES disparities has received considerable attention.[5,10–12,14–16] Behaviors are of interest because they are well-established risk factors for mortality,[16–20] are often patterned by SES,[21, 22] and are perceived as amenable targets for interventions. There is, however, little reason to believe that the explanatory role of behaviors is the same in different populations and over time within the same population. In many high income countries, there has been a behavioral “replacement” underway at the population level away from smoking and toward poorer diets and more sedentary lifestyles giving rise to increasing obesity.[23] Levels of SES disparities in cigarette smoking and other behaviors have also been documented to change over time within populations.[3, 24, 25]

Some prior estimates from the US and elsewhere indicate that behaviors are not the dominant factor in explaining SES mortality disparities, thereby suggesting that other primary mechanisms are at work.[6, 8,10–12] In contrast, findings from two recent studies indicate that behaviors play a dominant role, and suggest that earlier studies may have underestimated their importance.[14,15] The strength of these papers is that they were based on longitudinal data and explicitly accounted for within-person behavioral change. Stringhini et al.[15] suggest that the explanatory role of behaviors increases when they are treated as time-varying characteristics compared to when they are treated as fixed from a single baseline level. Using data from the British Whitehall II cohort, these authors found that four behaviors (smoking, alcohol consumption, diet, and physical activity) explained approximately 70% of occupational mortality differences, when considering information on behaviors collected repeatedly for each respondent (vs. 42% when they were treated as fixed).

A recent analysis of the Health and Retirement Study (HRS) using a composite SES index found that behaviors (smoking, drinking, and physical activity) explained 68% of SES mortality differences using marginal structural models (MSMs) to adjust for measured time-

varying confounding among health behaviors, SES, and mortality (vs. 53% in non-MSM models).[14]

The scientific and policy implications of these recent findings and the broader issue of how much disparities in health are a function of modifiable behaviors are quite profound. If newer estimates are better than prior ones, they move behaviors to the top of the priority list for understanding and reducing health disparities If the explanatory power of behaviors is more modest then behaviors are one of a broader set of factors that must be considered in research and policy in population health, and social disparities therein.

We examined whether the use of repeated measures of behaviors results in a reevaluation of the explanatory role of behaviors as suggested by recent papers.[14,15] We did so using data from a long running national sample of U.S. adults and evalauted differences with respect to both educational and income disparities.

Methods

Data

The American Changing Lives (ACL) Study is an ongoing survey conducted by the University of Michigan's Survey Research Center.[26–28] The response rate at inception in 1986 was 68% for individuals and 70% for households, and the study has re-interviewed approximately 80% of survivors in four subsequent waves: 1989, 1994, 2001/2, and 2011/12. Sample weights have been created to compensate for baseline nonresponse and between-wave attrition, keeping the sample representative of the U.S. non-institutionalized population in 1986 as they age. Our analysis included 3,617 individuals aged 25–96 in 1986 and used data from the 1986, 1989, 1994, and 2001/2 waves. The mean age in 1986 was 45.6 years. Mortality ascertainment was based primarily on the National Death Index (NDI), supplemented with reports from respondents, contact persons, and field workers and is as close to 100% as is possible or achieved in comparable studies (about 97% identification via NDI and 2–3% from other sources). A total of 1,832 deaths (51% of the sample) occurred during the mortality observation period of 1986–2011. The mean follow-up was 18.9 years. Our main outcome was all-cause mortality.

Measures

Education was measured as completed schooling years: 0–11, 12–15, and 16+. Income reflects the income of respondent and her/his spouse in 1986: <$10,000, $10,000–$29,999, and $30,000+; approximately poverty, between poverty and median income, and median or above.

We evaluated four behavioral factors: (1) Cigarette smoking (never, former, current); (2) physical activity as frequency of engagement with sports/exercise, walking, and garden/yard work, with respondents classified into quintiles of participation frequency; (3) alcohol consumption (nondrinkers, moderate [1 to <90 drinks per month for males and 1 to <60 for females], heavy [90+ and 60+ drinks for males and females, respectively]; (4) body mass index (BMI): underweight (<18.5), normal (18.5–24.9), overweight (25.0–29.9), obese (≥30). While BMI is not a behavior, we consider it a proxy for caloric imbalances

determined in large measure by behavior. Missing information was rare (<2%) and were handled by imputations using information from a recent wave or proxy reports.

Analysis

After providing descriptive characteristics, we estimated hazard ratios (HRs) from multivariate Cox proportional hazard models. Those alive on December 31st 2011 were censored. Models adjusted for background demographic factors: age (25–34, 35–44, 45–54, 55–64, 65–75, 75+), sex, and race (white, nonwhite). Our objective was to estimate the percentage of the association between SES (education and income) and mortality that can be accounted for by the behavioral factors after controlling for background factors. We do so by first estimating models that included the SES measure and background factors, but that excluded the behavioral factors (we refer to this as the "base" model). The estimated coefficients from these models indicate the total association of SES with mortality (after adjustment of background factors). A second set of models included the behavioral factors as fixed characteristics using their values reported in wave 1 (i.e., fixed models). A third set of models included the behavioral factors as time-varying incorporating information from all 4 waves (i.e., time-varying models). The coefficients for SES from the second and third sets of models indicate the SES-mortality association that is not accounted for by the behavioral and background factors (also referred to as a controlled direct effect). In addition to modelling all-cause mortality, we modelled specific death causes (CVD, cancer, other diseases [excluding external causes]).

To quantify the proportion of the total SES-mortality association that is accounted for by the behavioral factors, we calculated the percentage change in excess risks (hazard ratio [HR]-1.00) between the base model and, alternatively, the second (fixed behavioral factors) and third (time-varying behavioral factors) models.[29, 30] We focused on changes occurring between the lowest and highest educational (0–11 vs. 16+ years) and income (< $10,000 vs. $30,000+) groups. Confidence intervals for the percentage change were calculated using jackknife methods. Key assumptions that our approach makes is that there were no interactions between the behavioral factors and SES, and that the age, gender, and race control variables were sufficient to remove confounding between SES, the assessed health behaviors, and mortality.[31] Preliminary analyses revealed that there were no statistically significant (at the p=.05 level) interactions between each SES indicator and each behavioral factor, whether assessed as fixed or time-varying variables (except in the case of smoking and income in which we detected evidence that the risks of current, but not former, smoking was lower in lower income groups).

We performed a number of additional and supplemental analyses. We implemented sex-specific models (Appendix 1). We also estimated models that included the behavioral factors lagged by one wave and models that included adjustments for baseline health status (self-rated health and functional limitations). We additionally estimated MSMs as have Nandi et al.[14] Because time-varying behaviors such as health status can simultaneously serve as a mediator and a confounder between SES and death, conventional models might produce biased estimates of the controlled direct effect of SES on death risks.[32, 33] MSMs use weights to create a sample that is effectively randomized with respect to observed behaviors

at each previous wave, thus un-confounding the relationship between SES, behaviors, and death risk while allowing its mediating effect to still be assessed in the regression (marginal model).

Results

One-quarter had 0–11 years of education, 55% had 12–15 years, and 20% had 16+ years (Table 1). One-fifth had a 1986 income of <$10,000 and about 40% each had $10,000–$29,999 and $30,000+. The majority were current (30%) or former (28%) smokers. The majority were also moderate drinkers (54%). A small percentage (5%) was heavy drinkers. Nearly half were overweight/obese. Sex-specific analyses revealed that women were less likely to be former smokers and heavy drinkers compared to men. Levels of obesity, current smoking, and physical activity were similar across sex.

Table 2 shows the prevalence and odds ratios (ORs) of each behavioral factor by education and income. There were marked educational gradients in that those with lower education were more likely to be in a high risk category (e.g, current smoker, low physical activity, obese). The ORs comparing those with 16+ years of schooling to those with 0–11 years were in the range of 0.3–0.5 (reference: 0–11 years of schooling). Heavy alcohol consumption was an exception as the prevalence was about 5–6% across educational groups. Moderate drinking, often considered to be the optimal category, was more prevalent among those with higher education. Similarly, levels of the behavioral factors showed income gradients. The OR of current smoking for those with $30,000+ income was 0.6 (95% CI: 0.4, 0.8) with reference to those with <$10,000 1986 income, twice that of the OR between the lowest and highest educational groups.

The top of Table 3 shows results for education and income when each was included in a model without adjustment for the other. The HR for those with 0–11 schooling years (relative to 16+ years) was 1.88 (95% CI: 1.48, 2.39) in the base model. In the fixed model, the HR was reduced to 1.52 (95% CI: 1.20, 1.93). The time-varying model resulted in a further reduction to 1.44 (95% CI: 1.14, 1.83). The behavioral factors therefore statistically explained 41% (fixed, 95% CI: 26–55%) and 50% (time-varying, 95% CI: 30–70%) of the differential. Turning to income in the absence of adjusting for education, the HR for those with <$10,000 income was 2.09 (95% CI: 1.72, 2.56) in the base model (vs. $30,000+). Behavioral factors statistically explained 24% (fixed, 95% CI: 13%, 35%) and 39% (time-varying, 95% CI: 22%, 56%) of this differential.

Table 3 also shows results from models that included education and income simultaneously. The respective HRs in this base model were lower compared to the previous base models, although the HRs remained greater than 1.00 and statistically significant ($p<.05$). Behavioral factors statistically explained 49% (fixed; 95% CI: 20%, 77%) and 53% (time-varying; 95% CI: 15%, 91%) of the educational difference and 16% (fixed; 95% CI: 3%, 29%) and 33% (time-varying; 95% CI: 12%, 55%) of the income differential. Additional analyses examining differences between the bottom 20th percentile of income and the top 25th percentile of income ($40,000+), roughly the same percentile cut-points used for education, resulted in a similar mortality differential and explanatory role for behavioral factors.

Appendix 1 shows sex-stratified results. The key finding was that results were similar across sex.

Table 4 shows results for the individual contribution of each behavioral factor. Smoking and physical activity individually accounted for roughly one-fifth of the educational differential. Alcohol appeared to have a stronger explanatory role in the time-varying specification (18%; 95% CI: 7%, 30%) compared to the fixed specification (9%; 95% CI: 1%, 16%). The individual contributions was generally smaller to the income differential, reflecting the smaller overall attribution of behavioral factors to income versus educational differences.

Table 5 shows cause-specific results. For each cause, those with 0–11 schooling years had significantly ($p>.05$) higher mortality compared to those with 16+ years in the base model. Behavioral factors explained a somewhat higher percentage (58–83%) of CVD mortality differentials compared to other death causes. The explanatory role for cancer was about 27–29%. A similar pattern emerged for income in that behavioral factors tended to have a larger explanatory role for CVD mortality than other causes, although the CIs were wide.

Appendix 2 shows results for models restricted to baseline ages 35–54, the same range used in the prior Whitehall II study.[15] Behavioral factors explained up to 60% (95%: 24%, 95%) of the educational and income differentials. Appendix 3 shows results from models that a) lagged behavioral factors by 1 wave, b) included adjustments for baseline self-rated health and functional limitations, and c) were inverse-probability weighted models (i.e., MSM). Each of these models indicates that education and income remain significantly associated with mortality (i.e., the controlled direct-effect) after inclusion of behavioral factors supporting the conclusions from our primary analyses.

Discussion

Studies have suggested that modifiable behaviors explain anywhere from 15–75% of SES mortality differences.[6–10, 12–14, 16, 28, 34] Our results, found that key behavioral factors explained 40–50% of the mortality difference between low (0–11 years schooling) and high (16+ years) educational groups and about 20–40% between low (bottom 40^{th} percentile) and high (top 20^{th} percentile) income groups. Smoking and physical activity were the largest contributors to educational and income disparities.

Stringhini et al.[15], using the Whitehall II cohort, found that the use of repeated behavioral measures resulted in a near doubling of their explanatory role compared to the use of a single measure. In our sample, repeated treatment did not result in a significant increase in explanatory role. The period covered by our study and time between waves closely parallels that of Whitehall II. The studies do differ in important ways, which likely contributed to the divergent findings. Our estimates were based on adults ages 25+, while Stringhini et al.'s [15] were based on baseline ages 35–54. The majority (∼80%) of deaths in our sample occurred to those over age 70. Behavioral factors may be less consequential to disparities occurring at older ages as competing risks from many non-behavioral risk factors become more dominant. The differences in the age range also may have influenced the extent to which estimates differed by the treatment of behaviors as fixed or time-varying

characteristics. Our findings limited to baseline ages 35–54 suggested a stronger explanatory role to income differences in the time-varying specification compared to the fixed specification consistent with Stringhini et al.[15] Other differences included the behavioral factors examined. Strighini et al.[15] examined diet, while our study included obesity. The samples also differed in that Stringhini's et al.[15] sample was based on civil servants whose characteristics are not generalizable to a national population.[35] In contrast, our study was based on a sample designed to produce externally valid results for the U.S. non-institutionalized population.

Recently, Nandi et al.[14] reported that three behaviors (smoking, alcohol use, and physical activity) explained approximately half of the excess relative risk between the lowest and highest quartiles of a composite SES measure. These results, like ours, were based on time-varying behaviorial factors using simiar conventional techniques and were based on a U.S. national sample, but limited to ages 51–61 at baseline. Further, using MSMs increased the estimated explanatory power of behaviors in that study to 68%. A key difference between our study and Nandi et al. is that we evaluated education and income differences, seperately, and Nandi et al.[14] examined a single composite measure of SES that incorporated education, income, measures of occupation, labor force status, and wealth indicators.

Our results underscore that variations in the explanatory role of behaviors are a function of many parameters well beyond whether they are treated as time-varying or fixed characteristics. Cause-specific findings indicated that behavioral factors were more consequential to CVD deaths compared to other causes. Thus, the distribution of causes of death in a population, some of which is intrinsic to behaviors and some of which is not, will likely influence the behaviors' explanatory role. The lower attribution for cancer is likely a function of cancer being a heterogeneous group, with specific cancers being more related to behaviors compared to other cancers. We lacked sufficient power to examine more granular death causes. There were also few deaths in the sample from external causes (deaths=61) and these deaths may be linked to alcohol consumption and high-risk behaviors (e.g., illicit drug use) not examined and likely patterned by SES.[36, 37]

Behavioral factors had a larger role in explaining educational disparities compared to income disparities. This may be attributed to the somewhat stronger social patterning of the factors (specifically smoking) across education compared to income. Both SES indicators may shape risky behaviors over the life course through related and distinct pathways.[5, 10–12, 22, 38] Education may affect cognitive factors that influence both the uptake of information regarding the health impacts of various behaviors and the longer-term "discounting" (in economic parlance) or delay of gratification (in more psychological terms) involved in modifying behavior to achieve distal health benefits. Parental characteristics may additionally influence behavioral patterns through independent pathways.[5] Adult income will be linked to social and geographic environments during adulthood, exposing individuals to different social norms around health practices at work and other social settings.[5] Financial resources will also be related to the ability of accessing healthy foods and participating in recreational activity.

The education-mortality association is attenuated after inclusion of income, a finding confirming prior analyses.[10, 12] This should not signal that education is unimportant to mortality, but rather that education is predictive of lifetime occupational opportunities, the accumulation of financial resources, and the propensity to engage in risky behaviors. Moreover, financial resources can be susceptible to health during adulthood, which may upwardly bias its effects. We used baseline income, which reduces, but does not eliminate, such bias. Prior research addressing these statistical issues indicates independent effects of adult financial resources on the progression of health problems after onset.[39, 40] Nonetheless, our measure of income as a proxy for financial resources is imperfect (e.g., wealth may be a better indicator for those in retirement and income may not be as salient an indicator among young people early in career development).

We had limited power to produce reliable estimates at younger ages. The increases in putative explanatory power across specifications (fixed vs. time-varying) may not necessarily be a function of time-varying models being better suited to pick up period and age-related changes in behaviors, but may be a function of reverse causation bias. Behaviors are likely to vary over time in *response* to changes in health or treatment (e.g., medications precluding alcohol use). MSM analyses, while addressing time-varying confounding, must, like all observational-based approaches, assume that there are no unobserved covariates inducing such confounding that are not explained by the observed covariates. More detailed information on behaviors and a wider set of behaviors were unavailable. We did not have information on smoking intensity and no dietary information.

Our results underscore that the reasons for some of the diverging published estimates on the explanatory role of behaviors likely depend on a number of methodological parameters including the behavior(s) evaluated, SES indicators assessed, age range of the sample, and population under study. Ideally, then, assessments should be made using data that are current and reflective of national populations. We found that behavioral factors play an important role in contributing to SES mortality disparities, but other dominant mechanisms are likely at play. The production of SES health disparities are varied encompassing complex interplays of behavioral factors, healthcare access, psychosocial factors, and occupational and environmental hazards,[41, 42] the relative contributions of which likely vary across time and place. Each of these factors should be considered in a comprehensive set of policies aimed at improving population health and reducing disparities.

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Appendix 1

Contribution of behavioral factors collectively to educational and income differences in all-cause mortality. Sex stratified models; ages 25+ in 1986

Table A1.1

Men, (N=1,358)

	Hazard Ratios (95% CI)			% Explained (95% CI)	
Socioeconomic Status	*Behavioral Factors Excluded (Base Model)*	*Fixed Behavioral Factors, 1986 Value*	*Time-Varying Behavioral Factors*	*Fixed Behavioral Factors, 1986 Value*	*Time-Varying Behavioral Factors*
Education (0–11 vs. 16+ yrs.)	1.95 (1.37, 2.76)	1.53 (1.08, 2.18)	1.44 (1.01, 2.06)	44.2 (21.6, 66.8)	53.7 (22.2, 85.2)
1986 Income (<$10k vs. $30k+)	2.24 (1.66, 3.04)	2.02 (1.48, 2.74)	1.77 (1.30, 2.42)	17.7 (−0.43, 35.8)	37.9 (11.0, 64.8)
Joint Model					
Education (0–11 vs. 16+ yrs.)	1.48 (1.01, 2.16)	1.21 (0.83, 1.76)	1.20 (0.82, 1.75)	56.3 (6.6, 106.0)	58.3 (−6.3, 122.9)
1986 Income (<$10k vs. $30k+)	2.01 (1.41, 2.85)	1.96 (1.39, 2.77)	1.69 (1.19, 2.41)	5.0 (−16.5, 26.5)	31.7 (0.4, 63.0)

Note: The first two rows of results indicate models in which each measure of SES was evaluated without adjustment for the other. Joint models include both measures of SES. The reference category for education is 16+ years of schooling. The reference category for income is $30,000+. Behaviors assessed were cigarette smoking, physical activity, BMI, and alcohol use. Percent explanations are based on percentage reduction of the excess risks (HR-1.00) in the base model compared to the fixed and time-varying behavioral models, respectively. All models were adjusted for age, sex, and race. There were 670 deaths during 1986-2011. Results reflect sample weighting.

Table A1.2

Women, (N=2,259)

	Hazard Ratios (95% CI)			% Explained (95% CI)	
Socioeconomic Status	*Behavioral Factors Excluded (Base Model)*	*Fixed Behavioral Factors, 1986 Value*	*Time-Varying Behavioral Factors*	*Fixed Behavioral Factors, 1986 Value*	*Time-Varying Behavioral Factors*
Education (0–11 vs. 16+ yrs.)	1.74 (1.28, 2.36)	1.42 (1.06, 1.90)	1.38 (1.03, 1.85)	43.2 (20.9, 65.5)	48.6 (19.5, 77.7)
1986 Income (<$10k vs. $30k+)	1.92 (1.49, 2.47)	1.57 (1.23, 2.02)	1.50 (1.16, 1.94)	38.0 (20.9, 55.1)	45.7 (22.3, 69.1)
Joint Model					
Education (0–11 vs. 16+ yrs.)	1.39 (1.02, 1.89)	1.22 (0.90, 1.66)	1.21 (0.89, 1.65)	43.6 (3.8, 83.4)	46.2 (−5.4, 97.8)
1986 Income (<$10k vs. $30k+)	1.63 (1.25, 2.14)	1.42 (1.08, 1.86)	1.38 (1.04, 1.82)	33.3 (11.0, 55.6)	39.7 (7.9, 71.5)

Note: The first two rows of results indicate models in which each measure of SES was evaluated without adjustment for the other. Joint models include both measures of SES. The reference category for education is 16+ years of schooling. The reference category for income is $30,000+. Behaviors assessed were cigarette smoking, physical activity, BMI, and alcohol use. Percent explanations are based on percentage reduction of the excess risks (HR-1.00) in the base model compared to the fixed and time-varying behavioral models, respectively. All models were adjusted for age, sex, and race. There were 1,162 deaths during 1986–2011. Results reflect sample weighting.

Appendix 2

Contribution of behavioral factors collectively to educational and income differences in all-cause mortality. Limited to ages 35–54 at baseline in 1086 (N=981).

	Hazard Ratios (95% CI)			% Explained (95% CI)	
Socioeconomic Status	*Without Adjustment for Behavioral Factors*	*Fixed Behavioral Factors, 1986 Value*	*Time-Varying Behavioral Factors*	*Fixed Behavioral Factors, 1986 Value*	*Time-Varying Behavioral Factors*
Education (0–11 vs. 16+ yrs.)	2.53 (1.43, 448)	1.90 (1.06, 3.41)	1.62 (0.88, 2.97)	41.2 (12.4, 70.0)	59.5 (24.2, 94.8)
1986 Income (<$10k vs. $30k+)	2.35 (1.48, 3.74)	1.86 (1.18, 2.92)	1.57 (0.98, 2.52)	36.3 (10.6, 62.0)	57.8 (22.9, 92.7)
Joint Model					
Education (0–11 vs. 16+ yrs.)	2.07 (1.11, 3.84)	1.68 (0.90, 3.12)	1.51 (0.80, 2.83)	36.4 (0.9, 71.9)	52.3 (5.3, 99.3)
1986 Income (<$10k vs. $30k+)	1.79 (1.02, 3.13)	1.56 (0.94, 2.60)	1.38 (0.82, 2.33)	29.1 (−4.9, 63.1)	51.9 (−4.1, 107.9)

Note: Comparable models as those shown in Table 3 except restricted to respondents ages 35–54 at baseline in 1986. The first two rows of results indicate models in which each measure of SES was evaluated without adjustment for the other. Joint models include both measures of SES. The reference category for education is 16+ years of schooling. The reference category for income is $30,000+. Behaviors assessed were cigarette smoking, physical activity, BMI, and alcohol use. Percent explanations are based on percentage reduction of the excess risks (HR-1.00) in the base model compared to the fixed and time-varying behavioral models, respectively. All models were adjusted for age, sex, and race. All models were adjusted for age, sex, and race. There were 218 deaths between 1986–2011. Results reflect sample weighting.

Appendix 3

Sensitivity analyses of results shown to alternative specifications.

	Hazard Ratios (95% CI)			
Socioeconomic Status	*M1: Base model from Table 3 that excludes behavioral factors (N=3,617)*	*M2: Behavioral Factors lagged by one Wave (N=3,115)*[a]	*M3: Inclusion of baseline health status and behavioral factors (N=3,617)*[b]	*M4: Inverse probability weighted models (N=3,084)*[c]
Education (0–11 vs. 16+ yrs.)	1.88 (1.48, 2.39)	1.56 (1.20, 2.04)	1.34 (1.05, 1.71)	1.69 (1.03, 2.76)
1986 Income (<$10k vs. $30k+)	2.09 (1.72, 2.56)	1.61 (1.35, 1.90)	1.51 (1.23, 1.86)	1.78 (1.09, 2.90)

Note: Education and 1986 income estimated on separate models. All models include adjustments for age at baseline, sex, and race. Mortality linkage through 2011. The reference category for education is 16+ years of schooling. The reference category for income is $30,000+.

[a] M2 restricted to waves 2 (1989), 3 (1994), and 4 (2001/2). Model includes time-varying behavioral factors (cigarette smoking, physical activity, BMI, alcohol use) lagged by one wave.

[b] M3 based on all waves of data and includes an adjustment for self-rated health (excellent, very good, good, fair, poor) and functional health as reported at baseline (wave 1,1986). Functional health is coded according to degree of impairment: (1) Most impairment (in bed most of day or difficulty bathing self), (2) Moderate impairment (cannot climb a few flights of stairs or cannot walk several blocks), (3) Low impairment (difficulty or cannot do heavy work around house), and (4) No

impairment (little to some difficulty doing heavy work around the house). Behavioral factors (cigarette smoking, physical activity, BMI, alcohol use) were included as time-varying variables.

[c] M4 is estimated with an inverse probability-weighted marginal structural model using data from waves 2,3, and 4. M4 equation included controls for fixed confounders (age, race, sex) and the time-varying behavioral factors (cigarette smoking, physical activity, BMI, alcohol use). Observations with inverse probability weights in the top one percentile were excluded. The inverse probability weight was constructed by the formula ($w_i^E * w_i^I * w_{it}^O * w_{it}^S * w_{it}^{PA} * w_{it}^{ALC} * w_i^{ACL}$), where the subscripts *i* refers to an individual and *t* refers to survey wave, and:

(1) $w_i^E = Pr(E=e_i / Pr(E=e_i \mid C=c_i)$

(2) $w_i^I = Pr(I=i_i \mid E=e_i / Pr(I=i_i \mid E=e_i, C=C_i)$

(3) $w_{it}^O = Pr(O=O_{it} \mid E=e_i, I=i_i) / Pr(O=O_{it} \mid O=O_i(t\text{-}1), E=e_i, I=i_i C=c_i, R=r_{i(t-1)})$

(4) $w_{it}^S = Pr(S=Sit \mid E=e_i, I=i_i) / Pr(S=S_{it} \mid S=S_{i(t-1)}, O=O_{i(t-1)}, E=e_i, I=i_i C=c_i, R=r_{i(t-1)})$

(5) $w_{it}^{PA} = Pr(PA=pa_{it} \mid E=e_i, I=i_i) / Pr(PA=pa_{it} \mid PA=pa_{i(t-1)}, S=S_{i(t-1)}, O=O_{i(t-1)}, E=e_i, I=i_i C=c_i, R=ri_{(t-1)})$

(6) $w_{it}^{ALC} = Pr(ALC=alc_{it} \mid E=e_i, I=i_i) / Pr(ALC=alc_{it} \mid ALC=alc_{i(t-1)}, PA=pa_{i(t-1)}, S=S_{i(t-1)}, O=O_{i(t-1)}, E=e_i, I=i_i C=c_i, R=r_{i(t-1)})$

(7) w_i^{ACL} =American Changing Lives (ACL) survey wave 1 weight;

E=educational attainment
I=income in 1986
C=fixed confounders (age at baseline, race, sex)
R=health status (self-rated health and functional health)
O=BMI (normal weight, overweight, obese)
S=current smoker
PA=physical activity (5 quintiles)
ALC=alcohol use (non-drinker, moderate drinker, heavy drinker)

What is already known on this subject?

Prior estimates of the role of health behaviors in explaining socioeconomic (SES) disparities in mortality have varied considerably across studies, as have the samples studied, analytical approaches used, and measures of SES analyzed. Two recent studies indicate that behaviors may explain up to 70% of SES mortality differentials suggesting that earlier estimates were underestimated due to limitations in analytic models.

What this study adds?

We used a nationally representative sample and multiple analytical approaches to examine the role of behaviors to educational and income mortality differences. We show that the explanatory role of behaviors depends on a number of parameters including the SES measure assessed, the cause of death, and age range examined. We conclude that policies aimed at reducing social disparities should be comprehensive and encompass both behavioral and non-behavioral determinants.

Table 1

Sample characteristics, ages 25+ (N=3,617)

Characteristic	Percentage	Age- and sex-adjusted mortality, per 1000 PY[1]
Baseline, 1986		
Age, years		
25–34	29.0 (26.9, 31.1)	2.8 (1.9, 3.6)
35–44	23.2 (21.3, 25.2)	5.0 (3.7, 6.3)
45–54	14.6 (12.9, 16.2)	11.8 (9.2, 14.3)
55–64	13.8 (12.4, 15.1)	33.1 (28.8, 37.5)
65–74	12.5 (11.4, 13.5)	60.2 (55.0, 65.4)
75+	7.0 (6.2, 7.8)	121.2 (109.3, 133.2)
Sex		
Female	52.9 (50.7, 55.1)	7.8 (6.8, 8.8)
Male	47.1 (44.9, 49.3)	11.6 (10.0, 13.2)
Race		
White	83.4 (82.0, 84.9)	8.8 (7.7, 9.9)
Nonwhite	16.5 (15.1, 18.0)	12.2 (10.4, 14.1)
Educational Attainment, years		
0–11	25.6 (23.8, 27.3)	12.3 (10.5, 14.1)
12–15	54.7 (52.5, 56.8)	8.7 (7.5, 9.9)
16+	19.7 (17.9, 21.6)	6.8 (5.3, 8.2)
1986 Income, $		
<10,000	19.2 (17.7, 20.7)	13.3 (11.1, 15.5)
10,000–29,999	40.5 (38.4, 42.7)	9.5 (8.2, 10.8)
30,000+	40.3 (38.1, 42.5)	7.0 (5.9, 8.2)
Cigarette Smoking		
Current	30.4 (28.4, 32.4)	13.2 (11.2, 15.1)
Former	27.5 (25.6, 29.5)	8.9 (7.5, 10.4)
Never	42.1 (39.9, 44.2)	7.5 (6.5, 8.5)
Physical Activity		
Quintile 1 (low)	18.9 (17.3, 20.5)	12.6 (10.7, 14.6)
Quintile 2	20.7 (19.0, 22.4)	10.1 (8.4, 11.7)
Quintile 3	20.6 (18.8, 22.5)	9.1 (7.5, 10.7)
Quintile 4	18.5 (16.8, 20.2)	8.2 (6.6, 9.9)
Quintile 5 (high)	21.3 (19.5, 23.1)	6.9 (5.7, 8.2)
Alcohol		
Nondrinker	41.2 (39.1, 43.3)	10.3 (8.9, 11.7)
Moderate	53.6 (51.4, 55.7)	8.5 (7.3, 9.7)
Heavy	5.3 (4.3, 6.3)	11.3 (7.9, 14.6)
Body Mass Index (BMI)		
Underweight (BMI<18.5)	2.3 (1.7, 2.9)	16.7 (11.0, 22.5)

Characteristic	Percentage	Age- and sex-adjusted mortality, per 1000 PY[1]
Normal (18.5–24.9)	49.0 (46.8, 51.2)	8.7 (7.4, 10.0)
Overweight (25.0–29.9)	34.3 (32.2, 36.4)	9.0 (7.8, 10.2)
Obese (30.0+)	14.4 (13.0, 15.9)	11.4 (9.4, 13.4)
Mortality Follow-up, 1986–2011		
Unadjusted Death Rate, per 1,000 PY	16.6 (15.6, 17.7)	-
Deaths, Number	1,832	-
Person-Years (PY) of follow-up	2,726	-

Note: 95% confidence intervals shown in parenthesis. Results reflect sample weighting except for number of deaths and person-years of follow-up.

[1]Rates for age groups are sex adjusted and rates by sex are age adjusted.

Table 2

Age-adjusted educational and income gradients in behavioral factors at study baseline in 1986; ages 25+ (N=3,617)

	Educational Attainment, years			1986 Income, $		
Behavioral Factor	**0–11**	**12–15**	**16+**	**<10,000**	**10,000–29,999**	**30,000+**
Cigarette Smoking						
Current	42.9 (38.1, 47.6) Ref.	30.7 (28.0, 33.3) 0.6 (0.5, 0.7)	18.5 (14.6, 22.4) 0.3 (0.2, 0.4)	36.8 (32.1, 41.6) Ref.	32.1 (29.1, 35.2) 0.8 (0.6, 1.0)	26.2 (22.8, 29.5) 0.6 (0.4, 0.8)
Former	23.3 (19.8, 26.9) Ref.	28.4 (25.8, 31.1) 1.3 (1.0, 1.6)	28.9 (24.1, 33.6) 1.3 (0.9, 1.7)	25.3 (21.0, 29.6) Ref.	27.9 (25.0, 30.8) 1.1 (0.8, 1.5)	29.6 (25.9, 33.3) 1.2 (0.9, 1.6)
Never	33.7 (29.2, 38.3) Ref.	40.9 (38.1, 43.7) 1.36 (1.0, 1.7)	52.6 (47.5, 57.8) 2.2 (1.6, 2.8)	37.8 (33.3, 42.4) Ref.	40.0 (36.8, 43.1) 1.1 (0.8, 1.4)	44.2 (40.2, 48.2) 1.3 (1.0, 1.6)
Physical Activity						
Quintile 1 (low)	30.3 (26.0, 34.6) Ref.	17.5 (15.4, 19.7) 0.5 (0.4, 0.6)	9.6 (6.7, 12.5) 0.3 (0.2, 0.3)	27.0 (22.8, 31.1) Ref.	22.4 (19.7, 25.1) 0.8 (0.6, 1.0)	12.2 (9.6, 14.8) 0.4 (0.3, 0.5)
Quintile 5 (high)	15.2 (11.5, 18.8) Ref.	22.5 (20.1, 24.9) 1.6 (1.1, 2.1)	27.0 (22.6, 31.5) 2.1 (1.3, 2.8)	15.7 (11.9, 19.6) Ref.	19.7 (17.1, 22.3) 1.3 (0.9, 1.8)	26.5 (23.1, 29.9) 1.9 (1.3, 2.6)
Alcohol						
Nondrinker	56.5 (51.6, 61.4) Ref.	39.0 (36.2, 41.8) 0.5 (0.4, 0.6)	28.1 (23.7, 32.5) 0.3 (0.2, 0.4)	57.2 (52.4, 62.0) Ref.	44.5 (41.3, 47.7) 0.6 (0.5, 0.7)	30.3 (26.5, 34.0) 0.3 (0.2, 0.4)
Moderate	38.0 (33.2, 43.0) Ref.	55.7 (52.8, 58.5) 2.1 (1.6, 2.5)	65.6 (60.9, 70.3) 3.1 (2.2, 4.0)	37.5 (32.8, 42.1) Ref.	50.6 (47.4, 53.8) 1.7 (1.3, 2.1)	64.2 (60.3, 68.1) 3.0 (2.2, 3.8)
Heavy	5.5 (3.2, 7.8) Ref.	5.3 (4.0, 6.6) 1.0 (0.5, 1.4)	6.4 (3.6, 9.1) 1.2 (0.4, 1.9)	5.3 (3.0, 7.7) Ref.	4.9 (3.4, 6.4) 0.9 (0.4, 1.4)	5.5 (3.9, 7.1) 1.0 (0.5, 1.6)
Body Mass Index						
Normal (18.5–24.9)	43.7 (39.0, 48.4) Ref.	50.0 (47.2, 52.9) 1.3 (1.0, 1.6)	52.0 (47.1, 57.0) 1.4 (1.0, 1.8)	44.7 (39.7, 49.7) Ref.	49.4 (46.2, 52.6) 1.2 (0.9, 1.5)	52.0 (48.0, 55.9) 1.3 (1.0, 1.7)
Overweight (25.0–29.9)	33.1 (28.8, 374) Ref.	34.2 (31.6, 37.0) 1.1 (0.8, 1.3)	35.5 (30.6, 40.4) 1.1 (0.8, 1.4)	32.6 (28.0, 37.1) Ref.	32.3 (29.3, 35.3) 1.0 (0.7, 1.2)	35.5 (31.7, 39.3) 1.1 (0.8, 1.4)
Obese (30.0+)	19.9 (16.5, 23.3) Ref.	13.1 (11.2, 15.0) 0.6 (0.4, 0.8)	10.4 (7.2, 13.6) 0.5 (0.3, 0.7)	18.7 (15.3, 22.3) Ref.	15.9 (13.5, 18.3) 0.8 (0.6, 1.1)	10.4 (8.3, 12.5) 0.5 (0.3, 0.7)

Note: Percentages and odds ratios shown. 95% confidence intervals shown in parentheses. Results were age-adjusted using the mean age distribution of the educational and income groups, respectively. Results reflect sample weighting.

Table 3

Contribution of behavioral factors collectively to educational and income differences in all-cause mortality; ages 25+ (N=3,617)

	Hazard Ratios (95% CI)			% Explained (95% CI)	
Socioeconomic Status	***Behavioral Factors Excluded (Base Model)***	***Fixed Behavioral Factors, 1986 Value***	***Time-Varying Behavioral Factors***	***Fixed Behavioral Factors, 1986 Value***	***Time-Varying Behavioral Factors***
Education (0–11 vs. 16+ yrs.)	1.88 (1.48, 2.39)	1.52 (1.20, 1.93)	1.44 (1.14, 1.83)	40.9 (26.4, 55.4)	50.0 (29.6, 70.4)
1986 Income (<$10k vs. $30k+)	2.09 (1.72, 2.56)	1.83 (1.49, 2.23)	1.67 (1.36, 2.05)	23.9 (12.7, 35.1)	38.5 (21.5, 55.5)
Joint Model					
Education (0–11 vs. 16+ yrs.)	1.47 (1.14, 1.89)	1.24 (0.97, 1.60)	1.22 (0.95, 1.57)	48.9 (20.4, 77.4)	53.2 (15.3, 91.1)
1986 Income (<$10k vs. $30k+)	1.81 (1.44, 2.26)	1.68 (1.34, 2.10)	1.54 (1.23, 1.94)	16.0 (2.9, 29.1)	33.3 (12.1, 54.5)

Note: The first two rows of results indicate models in which each measure of SES was evaluated without adjustment for the other. Joint models include both measures of SES. The reference category for education is 16+ years of schooling. The reference category for income is $30,000+. Behaviors assessed were cigarette smoking, physical activity, BMI, and alcohol use. Percent explanations are based on percentage reduction of the excess risks (HR-1.00) in the base model compared to the fixed and time-varying behavioral models, respectively. All models were adjusted for age, sex, and race. There were 1,832 deaths during 1986–2011. Results reflect sample weighting.

Table 4

Contribution of individual behavioral factors to differences in all-cause mortality; ages 25+ (N=3,617)

	Hazard Ratios (95% CI)		% Explained (95% CI)	
Behavioral Factor	***Fixed Behavioral Factors, 1986 Value***	***Time-Varying Behavioral Factors***	***Fixed Behavioral Factors, 1986 Value***	***Time-Varying Behavioral Factors***
Education (0–11 vs. 16+ yrs.)				
Cigarette Smoking	1.71 (1.35, 2.17)	1.71 (1.35, 2.17)	19.3 (10.8, 27.8)	19.3 (10.7, 27.9)
Physical Activity	1.73 (1.35, 2.20)	1.67 (1.32, 2.11)	17.0 (8.4, 25.6)	23.9 (8.4, 39.4)
Body Mass Index	1.87 (1.47, 2.37)	1.89 (1.49, 2.40)	1.1 (−3.4, 5.6)	−1.1 (−6.4, 5.6)
Alcohol Use	1.81 (1.43, 2.30)	1.72 (1.36, 2.19)	8.6 (0.9, 16.3)	18.2 (6.7, 29.7)
All Behaviors	1.52 (1.20, 1.93)	1.44 (1.14, 1.83)	40.9 (26.4, 55.4)	50.0 (29.6, 70.4)
1986 Income (<$10k vs. $30k+)				
Cigarette Smoking	1.99 (1.64, 2.43)	1.99 (1.63, 2.43)	9.2 (3.2, 15.2)	9.2 (3.3, 15.1)
Physical Activity	1.98 (1.62, 2.42)	1.91 (1.56, 2.33)	10.1 (4.1, 16.1)	16.5 (1.9, 31.1)
Body Mass Index	2.05 (1.68, 2.50)	2.05 (1.68, 2.50)	3.7 (0.4, 7.0)	3.7 (−1.0, 8.4)
Alcohol Use	2.03 (1.66, 2.49)	1.91 (1.55, 2.34)	5.5 (−1.9, 12.9)	16.5 (6.6, 26.4)
All Behaviors	1.83 (1.49, 2.23)	1.67 (1.36, 2.05)	23.9 (12.7, 35.1)	38.5 (21.5, 55.5)

Note: Separate models estimated for each combination of SES indicator (education and income) and behavior. HRs for education reflect differences between those with 0–11 years of schooling compared to those with 16+ years of schooling (reference category). The HR for the model that excludes adjustment for behavioral factors was 1.88 (Table 3). For income, HRs reflect differences between those with less than $10,000 in income and those with $30,000 or more income in 1986 (reference category). The HR for the model that excludes adjustments for behavioral factors was 2.09 (Table 3). Percent explanations are based on percentage reduction of the excess risks (HR-1.00) in the base model compared to the fixed and time-varying behavioral models, respectively. All models were adjusted for age, sex, and race. There were 1,832 deaths during 1986–2011. Results reflect sample weighting.

Table 5

Contribution of behavioral factors collectively to educational and income differences in mortality from cardiovascular disease (CVD), cancer, and all other causes; ages 25+ (N=3,617)

	Hazard Ratios (95% CI)			% Explained (95% CI)	
Cause of Death	***Behavioral Factors Excluded (Base Model)***	***Fixed Behavioral Factors, 1986 Value***	***Time-Varying Behavioral Factors***	***Fixed Behavioral Factors, 1986 Value***	***Time-Varying Behavioral Factors***
Education (0–11 vs. 16+ yrs.)					
CVD	1.76 (1.14, 2.71)	1.32 (0.86, 2.03)	1.13 (0.71, 1.79)	57.9 (22.6, 93.2)	82.9 (31.4, 134.4)
Cancer	1.84 (1.06, 3.21)	1.60 (0.90, 2.82)	1.61 (0.88, 2.94)	28.6 (−2.6, 59.8)	27.4 (−22.9, 77.7)
All Other Diseases	2.36 (1.39, 4.01)	1.75 (1.05, 2.91)	2.02 (1.12, 3.62)	44.9 (22.3, 67.5)	25.0 (−16.0, 66.0)
1986 Income (<$10k vs. $30k+)					
CVD	2.00 (1.40, 2.83)	1.60 (1.13, 2.28)	1.52 (1.02, 2.27)	40.0 (19.8, 60.2)	48.0 (14.3, 81.7)
Cancer	1.59 (0.98, 2.58)	1.47 (0.90, 2.38)	1.31 (0.81, 2.13)	20.3 (−15.5, 56.1)	47.5 (−29.8, 134.8)
All Other Diseases	4.10 (2.44, 6.89)	3.23 (1.92, 5.44)	3.66 (2.05, 6.53)	28.1 (14.2, 42.0)	14.2 (−14.5, 42.9)

Note: The first two rows of results indicate models in which each measure of SES was evaluated without adjustment for the other. Joint models include both measures of SES. The reference category for education is 16+ years of schooling. The reference category for income is $30,000+. Behaviors assessed were cigarette smoking, physical activity, BMI, and alcohol use. Percent explanations are based on percentage reduction of the excess risks (HR-1.00) in the base model compared to the fixed and time-varying behavioral models, respectively. All models were adjusted for age, sex, and race. Deaths were assessed through 2006. All other disease category excludes deaths from external causes (n=61). There were 586 CVD, 288 cancer, and 383 deaths from other diseases.