NBER WORKING PAPER SERIES

THE CONTRIBUTION OF BEHAVIOR CHANGE AND PUBLIC HEALTH TO IMPROVED U.S. POPULATION HEALTH

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Working Paper 20631
http://www.nber.org/papers/w20631

NATIONAL BUREAU OF ECONOMIC RESEARCH
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October 2014

This paper was prepared for the National Institute of Health Office of Behavioral and Social Sciences Research (NIH OBSSR), for inclusion in a publication entitled Review of Behavioral and Social Sciences Research Opportunities: Innovations in Population Health Metrics. This work was supported by National Institute on Aging (NIA) research grant P01 AG31098. We are grateful to Kaushik Ghosh and Jean Roth for advice and assistance with data analysis. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

At least one co-author has disclosed a financial relationship of potential relevance for this research. Further information is available online at http://www.nber.org/papers/w20631.ack

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NBER Working Paper No. 20631
October 2014
JEL No. I1,I10,I12,I18

ABSTRACT

Adverse behavioral risk factors contribute to a large share of deaths. We examine the effects on life expectancy (LE) and quality-adjusted life expectancy (QALE) of changes in six major behavioral risk factors over the 1960-2010 period: smoking, obesity, heavy alcohol use, and unsafe use of motor vehicles, firearms, and poisonous substances. These risk factors have moved in opposite directions. Reduced smoking, safer driving and cars, and reduced heavy alcohol use have led to health improvements, which we estimate at 1.82 years of quality-adjusted life. However, these were roughly offset by increased obesity, greater firearm deaths, and increased deaths from poisonous substances, which together reduced quality-adjusted life expectancy by 1.77 years. We model the hypothetical effects of a 50% decline in morbid obesity and in poisoning deaths, and a 10% decline in firearm fatalities, roughly matching favorable trends in smoking and increased seat belt use. These changes would lead to a 0.92 year improvement in LE and a 1.09 year improvement in QALE. Thus, substantial improvements in health by way of behavioral improvements and public health are possible.

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While health is often thought of in terms of diagnosed medical conditions, it is modifiable behavioral risk factors such as obesity and smoking that account for the largest portion of deaths each year.[1,2] For example, Mokdad et al.[1] report that in 2000, 43% of total deaths were accounted for by six behavioral risk factors: smoking (18%), obesity (17%), alcohol consumption (4%), motor vehicle accidents (2%), firearms (1%), and illicit drug use (1%).

In addition to affecting mortality, these modifiable behavioral factors have significant effects on health-related quality of life (HRQOL).[3,4,5,6] Smoking, heavy alcohol use, and obesity have been causally linked to a myriad of diseases and symptoms,[6,7,8] and injuries from motor vehicle accidents and firearms can be severe. When feasible, considering this nonfatal impact can provide a more comprehensive picture of the health outcomes attributable to these factors.

Behavioral and public health interventions have been very successful in reducing the harms of some of these factors.[1,9] Deaths from smoking and (to a lesser extent) motor vehicle accidents have declined markedly over time.[9] Other factors, such obesity[1] and drug overdose,[10] have worsened. On net, there is little understanding of how these risk factor changes as a whole have contributed to U.S. health trends.

This paper examines the effects of changes in six major behavioral factors on HRQOL and mortality from 1960 to 2010: smoking, obesity, heavy alcohol use, and unsafe use of motor vehicles, firearms, and poisonous substances. For the factors that have improved, we evaluate how much improvement there has been in length and quality of life. For those that have deteriorated, we simulate the hypothetical gain achievable through effective public health interventions and behavioral change targeting these factors.

In each case, we try to differentiate medical from non-medical changes. In the case of smoking, for example, cigarette consumption has declined by over half, and medical care has extended life for people with cardiovascular disease.[11] Our primary focus is on the non-medical changes. We separate the medical from the non-medical changes as we are able to do so. Unfortunately, we generally do not have enough evidence to differentiate amongst sources of non-medical improvement or decrement: behavioral health, public health measures, or other causes.

Methods

For each of the six behavioral risk factors that we considered-- smoking, obesity, heavy alcohol use, and unsafe use of motor vehicles, firearms, and poisonous substances--our goal was to measure changes in health-related quality of life, including both mortality and morbidity, over the past several decades.

The data sources and methods for each of the risk factors that we considered are shown in Table 1. For smoking, obesity, and alcohol use, we had consistent measures of prevalence over time, and could examine the effects of both fatal and nonfatal exposures. For these conditions, there were multiple steps to the analysis: measuring the historical trend in the prevalence of the risk factor, and evaluating how it has affected both length and quality of life. We describe each of these further below.

Table 1: Methods and Data Sources for Risk Factors Considered

	Mortality and HRQOL			**Mortality**		
	Obesity	Smoking	Alcohol	Motor Vehicles	Firearms (suicide /homicide)	Accidental Poisoning
Methods	Public health affects prevalence. Effects of risk factor on mortality and QOL measured in national data and held constant over time.			Public health affects both prevalence and the effect of risk factor on mortality over time; actual mortality used. QOL difficult to account for due to changing pool of nonfatal exposures.		
Data for Prevalence	NHANES, NHES	NHIS	NHANES	n/a		
Data for impact on Mortality	NHANES mortality follow-up			n/a		
Data for actual deaths	n/a			Vital statistics		
Data for impact on HRQOL	MEPS	MEPS	NHIS	n/a		

Notes: HRQOL = health-related quality of life; MEPS = Medical Expenditure Panel Survey; NHANES = National Health and Nutrition Examination Survey; NHES = National Health and Examination Survey; NHIS = National Health Interview Survey; QOL = quality of life.

For motor vehicle accidents, firearms, and accidental poisoning, there are multiple underlying behaviors and factors that can affect a person's risk. For example, in the case of motor vehicles, these can include reckless, distracted, or impaired driving, failure to use a seat belt, and the safety features of roads and vehicles.[12] For firearms, they include factors such as secure storage, locking devices, safety training, community-based prevention, identification of individuals at risk of misuse, and laws regarding firearm acquisition and possession.[13,14] These factors can be difficult or impossible to track reliably over time, and they can affect both the risk of an incident and the extent of resulting injury. In addition, for nonfatal motor vehicle accidents, firearm injury, and drug misuse, HRQOL is difficult to account for due to a lack of consistent data on non-fatal outcomes and to changes over time in the number and severity of injuries. Thus, as a measure of the effect of these risk factors over time, we used mortality data from U.S. vital statistics.[15] Motor vehicle deaths include those resulting from collisions of all types of road vehicles, including collision of these vehicles with pedestrians and bicycles. For firearm deaths, we considered homicides and suicides. In the accidental poisoning category, the vast majority of deaths since the 1980s were due to unintentional overdose of prescription or illicit drugs; the remainder resulted from exposures to other substances such as alcohol, noxious fumes and ingested chemicals. Since we used data on mortality only, we omitted quality of life estimates for these factors.

Motor Vehicle Accidents, Firearms, and Poisoning--Trends and Assessment. We began by measuring trends in mortality from motor vehicle accidents, firearms, and accidental poisoning, for all years from 1960 through 2010. To adjust for changes in the definition of motor vehicle deaths in the different versions of the International Classification of Diseases used over this period (ICD-7, 8, 9, and 10), we used comparability ratios provided by National Center for Health Statistics (NCHS).[16,17,18] Comparability ratios were not provided for the subcategories of firearm suicide and homicide, however these deaths are more straightforward to measure over time, and comparability ratios for the broader categories of suicide and homicide were close to 1. For poisoning, comparability ratios were not provided by NCHS due to insufficient sample sizes for stable estimates. However, specific categories of poisoning match well over time. Thus, we followed the method of a prior study examining child poisoning,[19] using accidental poisoning by

solid and liquid substances in all years and excluding deaths from poisonous vapors and gases, which includes carbon dioxide poisoning.

Modeling the Portion of Change due to Medical Care. An important consideration when using mortality as a proxy for exposure to these risk factors is that there are medical contributions to survival. Advances in trauma care have reduced the probability of death from motor vehicle collisions, drug overdoses, and shootings. The proportion of population health improvement attributable to medical care is unknown, with varying estimates derived or used in the literature, including 10, 20, and 50%.[20,21,22] The proportion also depends on whether improved access to medical care is counted as part of medical improvement or as public health improvement. For example, improvements in emergency response such as 'enhanced 911' (which provide the precise location of callers) have sped up response times and improved patient survival.[23,24]

To address this uncertainty, we used the approximate median of the existing estimates and assumed that 25% of the mortality improvements for motor vehicle accidents and poisonings have resulted from medical care. (We did not assume a medical contribution to reduced firearm deaths since gun suicides are nearly always fatal and comprised over half of firearm deaths. Also, and the analysis did not allow estimation of a contribution of medical care to only the homicide portion of deaths in the firearm category.) We performed sensitivity analyses using values of 10% and 50% for the contributions of medical care to mortality change, with any remaining improvement attributable to behavioral and public health factors. In the case of motor vehicle accidents, these include impaired driving prevention and surveillance, seat belt and child safety seat use, graduated driver licensing, vehicle and road safety advances, and many more. For prevention of drug overdose, interventions are being designed at the federal, state, local, and insurance company level to address and prevent dangerous prescription drug addictions.[10,25,26,27]

Prevalence and Effects of Smoking, Obesity, and Heavy Alcohol Use. To measure the historical distribution of body mass index (BMI), we used physical measures of height and weight from the National Health and Nutrition Examination Survey (NHANES)[28] a comprehensive national health survey that combines interviews with physical examinations. We also used its precursor, the National Health and Examination Survey (NHES). Respondents were classified using World

Health Organization (WHO) criteria[29] as underweight (BMI < 18.5 kg/m^2), normal weight (18.5 to 24.9 kg/m^2), overweight (25.0 to 29.9 kg/m^2), obese (30.0 to 34.9 kg/m^2, WHO obesity class I), or morbidly obese (≥ 35.0 kg/m^2, WHO obesity classes II and III).
Sample size considerations do not permit exact estimation of BMI by single year of age, which is needed for the mortality estimates. To form estimates by single year of age, we used regression analysis to assess the likelihood of being in each BMI category based on age, gender, race, and their interactions and predicted the distribution of categories by year of age for each time period covered by the data: 1959-1962 (NHES), 1971-75 (NHANES I) 1976-1980 (NHANES II), 1988-1994 (NHANES III), and the continuous NHANES (2000-2010, in 2-year cycles). In essence, this just smooths the observed data across nearby ages.

To measure the historical distribution of current and former smoking, we used data from the National Health Interview Survey (NHIS), an ongoing health survey of the U.S. civilian non-institutionalized population.[30] Current smokers and former smokers were defined as those who had ever smoked at least 100 cigarettes and who still smoked, or had quit, respectively. Smoking rates were predicted by year of age in 1965 (the first year in which smoking questions were asked in the NHIS) and 2010. To estimate smoking rates by single year of age, we used the same smoothing process as described above for BMI.

We measured the prevalence of alcohol use in NHANES I (1971-75), NHANES III (1988-1994) and in the continuous NHANES (2000-2010, in 2-year cycles). (Alcohol was not asked about in the 1959-62 NHES, and we did not use NHANES II due to a difference in alcohol measurement in that year.) We defined heavy alcohol use as 15 or more drinks per week for men and 8 or more drinks per week for women, consistent with the Centers for Disease Control and Prevention (CDC) definition.[31] As with BMI and smoking, smoothed heavy alcohol use rates were predicted by year of age from a regression of heavy drinking on age, gender, race, and their interactions.

To measure how each of these risk factors affects length of life, we estimated Cox proportional hazard models relating each risk factor to subsequent all-cause mortality, controlling for age, race, gender, and their interactions. For this we used data from the combined NHANES I, II, and

III surveys, matched to subsequent death records (through 1992 for NHANES I and II and 2006 for NHANES III).

To estimate the impact of BMI and smoking on HRQOL, we used data from the 2002 Medical Expenditure Panel Survey (MEPS),[32] which measures health status, medical expenditures, and socioeconomic characteristics in a sample nationally representative of the U.S. community population. Following a method that we previously developed,[33] we related each risk factor separately to a 100-point rating of overall health (the 'visual analog scale' from the Euroqol EQ-5D[34] health measurement instrument), controlling for age, gender, and race. From this we predicted HRQOL weights for each risk factor by 10-year age group.

To estimate the effects of heavy alcohol use on HRQOL, we used data from the 2010 NHIS. The NHIS does not contain a 100-point self-rating of health, but it does include a large number of impairments and symptoms that enabled the estimation of HRQOL scores using techniques that we developed in previous work.[33,35] First, we identified the full set of impairments and symptoms asked in both NHIS and MEPS: depressive symptoms, anxious symptoms, and limitations in primary activity (e.g. work), self-care (activities of daily living), routine needs (instrumental activities of daily living), walking, bending, standing, dexterity, vision, and hearing. We then regressed the 100-point rating of overall health in MEPS on this set of impairments and symptoms. Using these regression coefficients, we calculated predicted HRQOL scores using this same set of impairments and symptoms in the NHIS data. Previous analyses[33] supported holding constant the impact of each impairment and symptom over time, since the effect of a particular impairment on HRQOL remains relatively stable over time, whereas its prevalence can change more rapidly.

Life Expectancy and QALE Calculation. To calculate life expectancy at age 18, we used U.S. life tables for the base year, 1960 (1973 for alcohol).[36,37] To measure change in life expectancy through 2010 due to each risk factor, we used the 2010 mortality rate for that risk factor, otherwise holding life expectancy constant at the 1960 level (1973 for alcohol). This provided an estimate of the life expectancy change that would have occurred if only this risk factor had changed. For obesity, smoking, and alcohol, the 2010 mortality rate was the product of the

relative risks of mortality associated with each risk factor and the predicted share of the population with the risk factor at each year of age in that year.

To calculate quality-adjusted life expectancy (QALE), mean HRQOL for each 10-year age group was used to adjust remaining life expectancy at each age. For motor vehicle accidents, firearms, and poisoning, where we were able to measure mortality but not quality of life, in order to also obtain a QALE value, we calculated QALE using the rough assumption that HRQOL remained constant over time. Since not all years are in perfect health, this reduces the quantity of quality-adjusted life years relative to life years. To place a dollar value on QALE, we valued each year of life at $100,000 and used a 3% discount rate for future years lived.

Finally, for those factors found to have worsened rather than improved over time, we performed simulations of the potential benefit of successfully curbing these problems. Based on what was achieved for factors that improved, we modeled the effects of similar improvements for the factors that did not improve, simulating the hypothetical effect of this progress.

Results

Trends in Behavioral Risk Factors

Of the six factors that we examined, three improved: smoking, motor vehicle deaths, and alcohol use. The others – obesity, firearms, and poisoning – worsened over time. Table 2 shows the percentage change in prevalence or the deaths from each risk factor over time, age-adjusted to the 2000 population. Smoking prevalence and motor vehicle deaths showed the largest declines, while obesity and poisoning showed the greatest increases. Figure 1 (a-g) shows the trends in each factor, age-adjusted to the year 2000 population. Smoking is the leading preventable cause of death; a regular smoker has a life expectancy that is about 7 years below that of a never smoker.[7] Figure 1a shows the smoking rate among US adults over time. The rate declined by more than half, from 42% in 1965 to 19% in 2010.[38]

Motor vehicle accident deaths have also declined over time, as shown in Figure 1b. Unadjusted, the decline was 46%. However, more people had cars over time, and vehicle miles driven

Table 2: Percent Change in Each Risk Factor

	Percent Change in Prevalence, 1960-2010†
Smoking	-54%
Heavy Alcohol Use	-22%
Obesity (BMI ≥ 30)	161%
	Percent Change in Deaths, 1960-2010
Motor Vehicles	-46%*
Firearm Suicide	4%
Homicide	25%
Accidental Poisoning (primarily drug overdose)	1005%

†Heavy alcohol use change is from 1973-2010. *Accounting for the increase in miles driven over this time period, motor vehicle deaths would have increased by 234% if the death rate per mile had not changed. Percent change in each factor using rates that are adjusted to the age distribution of the population in the year 2000, to account for changes in the age distribution of the population over time.

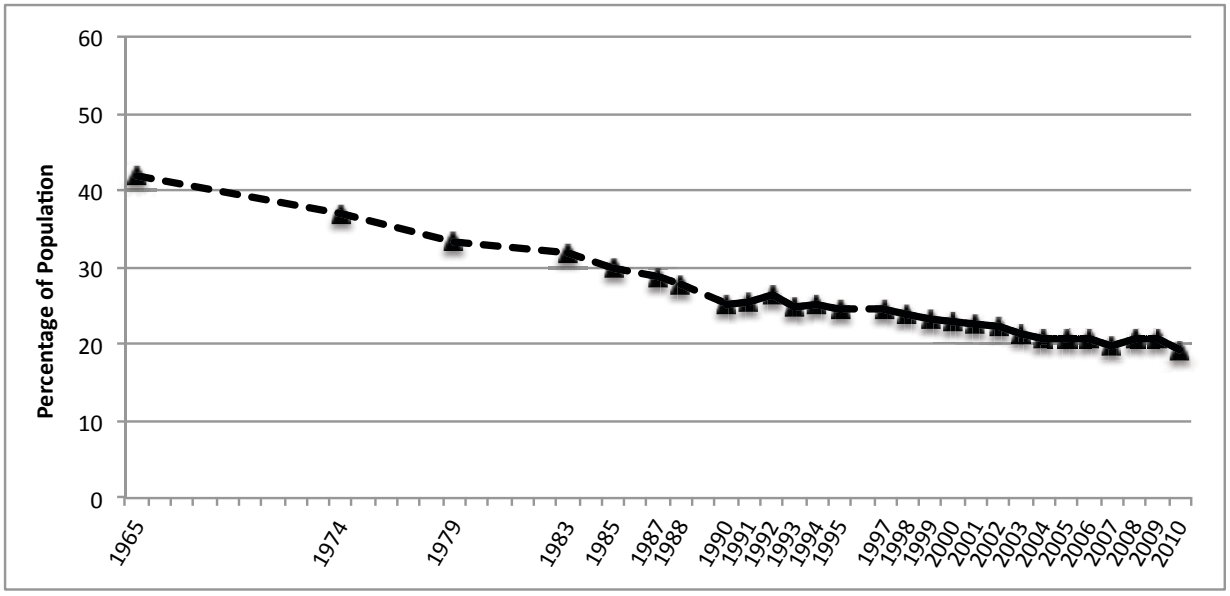
increased markedly. Thus, Figure 1b also shows a counterfactual mortality rate assuming no change in deaths per mile during this time of increased driving. That mortality rate is forecast to have increased by 234%. Thus, the net reduction in motor vehicle mortality adjusted for miles driven was 280%. This is believed to result from many successful public health interventions, including safer automobiles and roads and enforcement of seat belt laws, motorcycle helmet laws, graduated driver licensing, and impaired driving laws and penalties.[12,39]

Heavy use of alcohol has declined over time (Figure 1c). The change from 1971-75 to 2009-10 was -22% in relative terms, or 3 percentage points. Given the relatively low relative risk for heavy drinking and small change in heavy drinking prevalence, this did not contribute a great amount to population health.

Obesity has increased over time (Figure 1d); among behavioral risks, this is the major contributor to worse health. The share of the population that is obese or morbidly obese increased from 14% in 1959-62 to 36% in 2009-10. The increase in obesity is attributed to many causes, including reductions in the time cost of food preparation.[40]

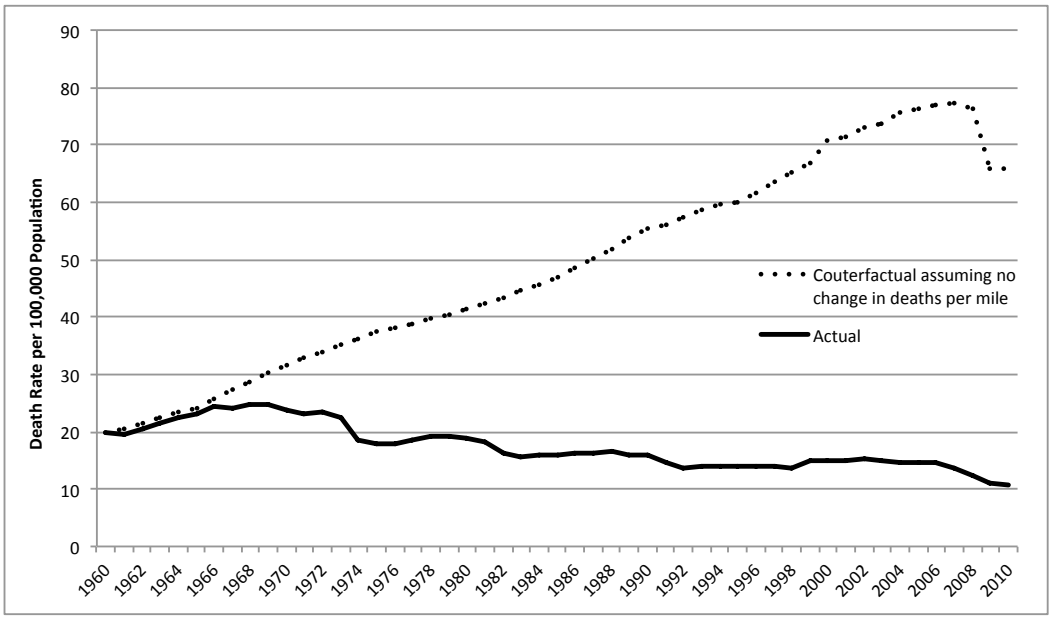
Firearm suicide and homicide (Figure 1e) increased into the 1970s and declined in the 1990s. Firearm homicides also declined in the mid-1970s and 1980s, but rose again in the late 1980s and early 1990s. This rise is largely attributed to the crack-cocaine drug epidemic at that time.[41]

Figure 1a: Trend in Current Smoking from NHIS data, Age 18+, 1965-2010



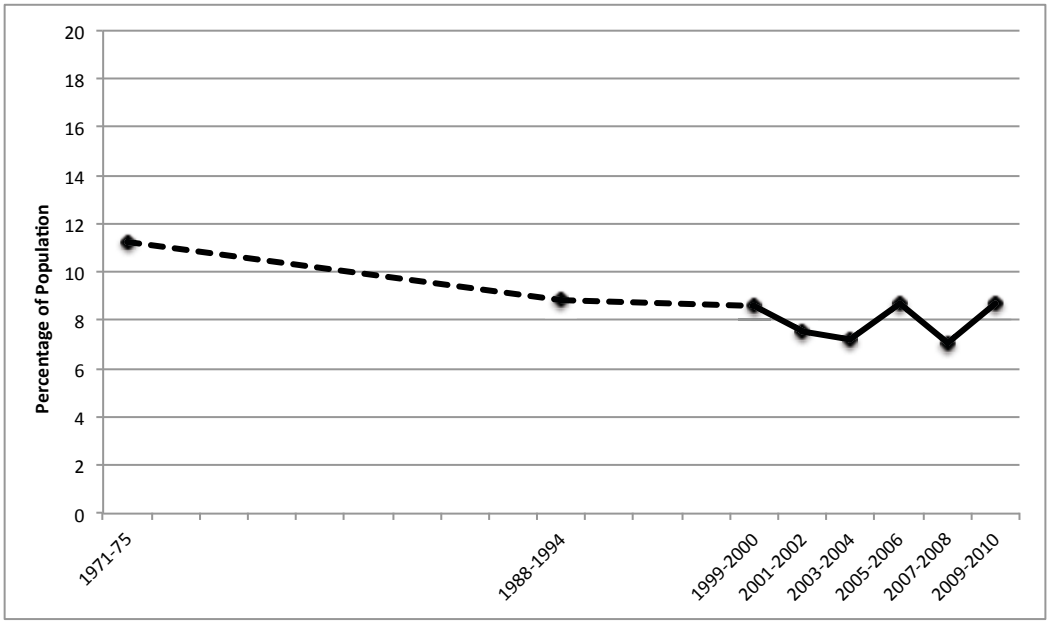
Note: Current smokers were those who had ever smoked at least 100 cigarettes and still smoked, as reported in the National Health Interview Survey (NHIS). These rates, age-adjusted to the 2000 population, are directly from the following publication: National Center for Health Statistics. Health, United States, 2011: With Special Feature on Socioeconomic Status and Health. Hyattsville, MD. 2012.

Figure 1b: Trend in Mortality Rate from Motor Vehicle Accidents, 1960-2010



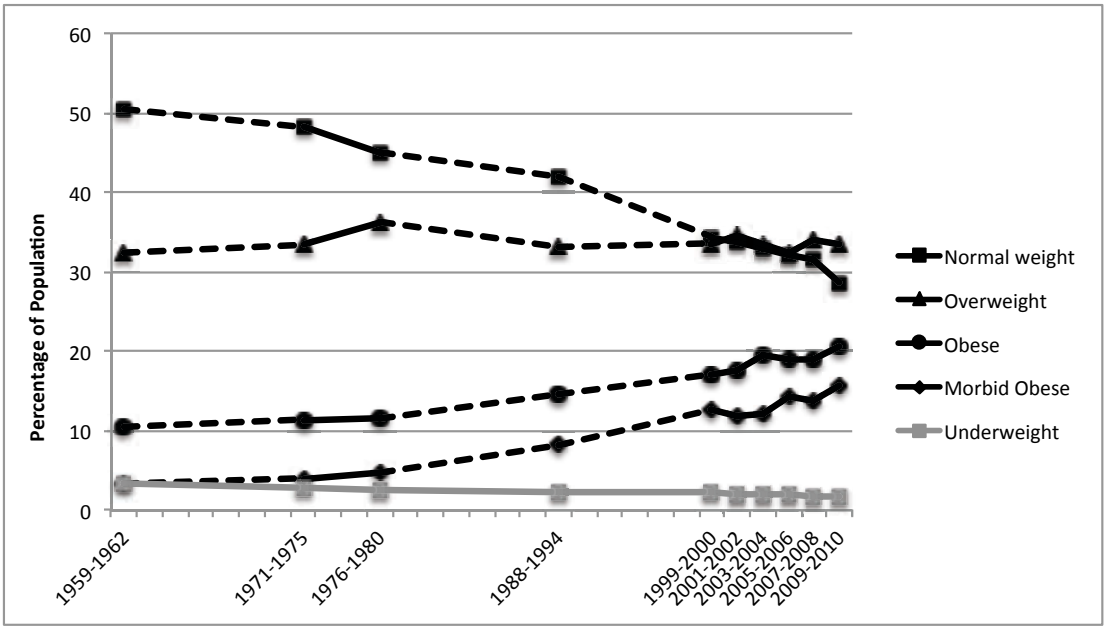
Note: Mortality rates from U.S. vital statistics are adjusted for changes in the age distribution of the population over time and for changes to the definition of motor vehicle accident (MVA) mortality across ICD (International Classification of Diseases) versions 7-10. Includes deaths resulting from collisions of all types of road vehicles, including collision of these vehicles with pedestrians and bicycles. The counterfactual trend reflects the increase in deaths that would have occurred if the death rate per mile had remained at the 1960 rate while driving rates (number of miles driven) increased over time. The drop in this trend in 2007-2009 reflects a decline in miles driven, coinciding with the Great Recession.

Figure 1c: Trend in Heavy Alcohol Use, Age 25+, NHANES 1973-2010



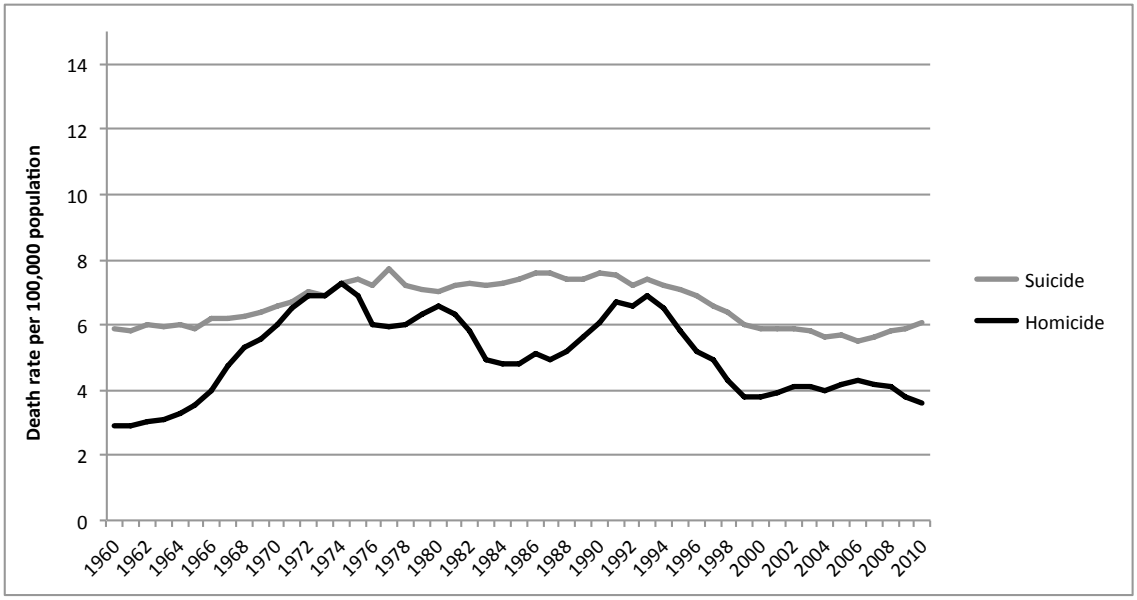
Note: Heavy alcohol use is defined as 15+ drinks/week for men and 8+ drinks/week for women, as reported in the National Health and Nutrition Examination Survey (NHANES). Rates in each year are age-adjusted to the 2000 population. Note difference in scale compared to Figures 1a and 1d.

Figure 1d: Trends in Body-Mass Index Distribution, NHES/NHANES, 1960-2010.



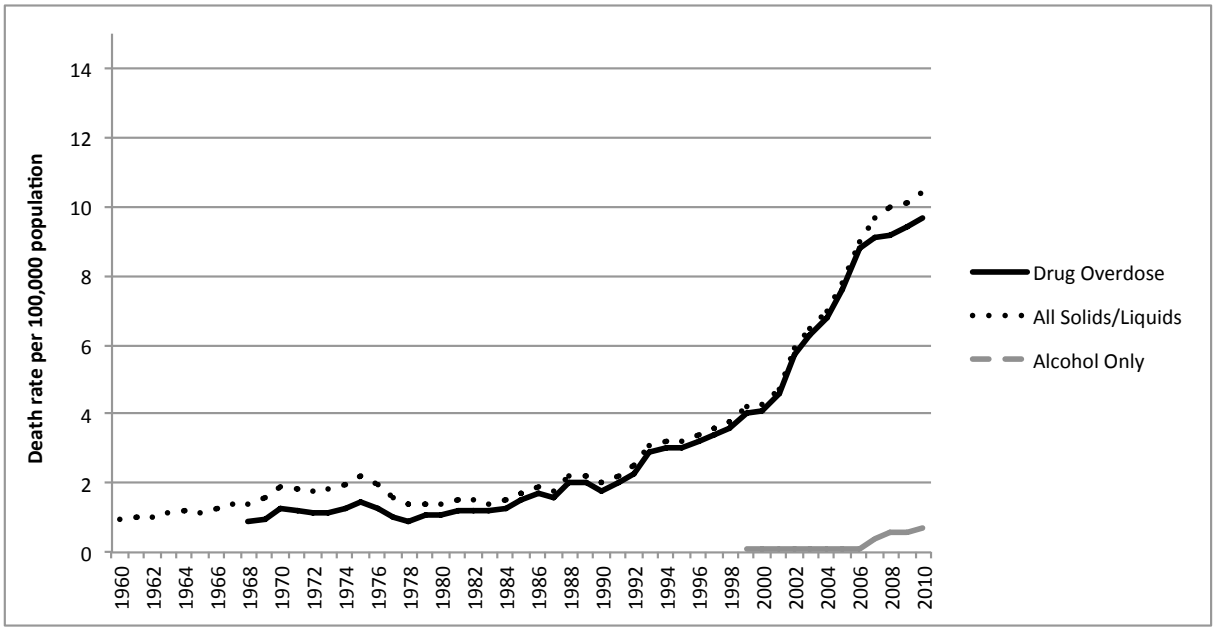
Note: Categories of body-mass index (BMI, the weight in kilograms divided by the square of the height in meters) were defined according to the World Health Organization criteria: underweight (BMI <18.5), normal weight (BMI 18.5 to 24.9), overweight (BMI 25.0 to 29.9), obese (BMI 30.0 to 34.9; obesity class I), and morbidly obese (BMI ≥35.0; obesity classes II and III). Underweight is shown in figure but not used in calculating life expectancy because low BMI can be indicative of pre-existing illness.[42] Data are from the National Health Examination and the National Health and Nutrition Examination Survey (NHANES). Rates in each year are age-adjusted to the 2000 population.

Figure 1e: Trend in Mortality Rate from Firearm Suicide and Homicide, 1960-2010



Note: Includes intentional self-harm and assault using all types of firearms, from U.S. vital statistics. Rates in each year are age-adjusted to the 2000 population. Note difference in scale compared to Figure b.

Figure 1f: Trend in Mortality Rate from Accidental Poisoning, 1960-2010



Note: Mortality rates from U.S. vital statistics. Drug overdose includes accidental death from prescription, over-the-counter, and illicit "drugs, medicaments and biological substances."[43] The broader category of deaths due to accidental "poisoning by and exposure to all solids and liquids" includes these drug substances as well as alcohol, pesticides, "organic solvents and halogenated hydrocarbons and their vapours", and "other and unspecified chemicals and noxious substances", but excludes deaths due to "other gases and vapors"[44] Rates in each year are age-adjusted to the 2000 population. Note difference in scale compared to Figure b.

Firearm homicides have declined by nearly 50% since that peak in the 1990s.[45] Firearm homicides changed little through the 2000s, and declined in the most recent years. Firearm suicides declined slightly in the mid-2000s, with an uptick in the most recent years. The net change over the past half-century was a slight increase 0.7 percentage points for gun homicide and 0.2 percentage points for gun suicide.

Finally, deaths due to poisoning (Figure 1f) increased dramatically over the past 20 years. The vast bulk of this is overdose of drugs, particularly prescription opioid medications, which has more than quadrupled since 1999.[10,46] This increase overwhelmed a decline in infant and child poisoning since the 1960s (findings by age not shown). Poisoning deaths do not include intentional suicides or deaths due to accidents of undetermined intent, which are measured separately by the CDC. While the dramatic rate of increase in drug deaths slowed slightly from 2006 to 2010, during this time the rate of alcohol poisoning suddenly increased among all age groups. Explanations for this include increased frequency of binge drinking during the Great Recession of late 2007 to mid-2009,[47] and increased use of caffeinated energy drinks containing alcohol; these energy drinks increase consumption of alcohol during binge drinking by masking the depressive effect of alcohol.[48]

Changes in QALE

Table 3 shows relative risks of all-cause mortality by smoking status, BMI status, and alcohol consumption calculated using separate Cox proportional hazards models for each risk factor. Current smokers had the greatest relative risks of death, followed by those who were morbidly obese and heavy drinkers. The effects on HRQOL of smoking, BMI category, and heavy alcohol use are shown in Table 4. As expected, mean quality of life was worse for current smokers than never smokers. Those in the morbid obese category had HRQOL similar to smokers. The HRQOL of those in the obese category was higher than for smokers but not as high as that of those in the normal weight or overweight categories. Heavy alcohol users had HRQOL scores essentially the same as non-heavy users.

The changes in life expectancy (LE) and QALE for each risk factor that we estimate to be attributable to public health interventions and behavioral change are shown in Table 5, which

Table 3: Hazard Ratios: Relative Risks of Death from all Causes among Respondents Aged 25-70 in NHANES I, II, and III Linked Mortality Data

		Attained age under 65	Attained age 65+
Body Mass Index N= 35,542 (50% age 65+) Deaths: 1,340/ 8,609	Normal weight	1.00	1.00
	Overweight	0.76	0.87
	Obese	1.08	1.05
	Morbid obese	1.77	1.50
Smoking N = 29,408 (51% age 65+) Deaths: 1,097 / 6,666	Never smokers	1.00	1.00
	Former smokers	1.08	1.26
	Current smokers	2.51	2.52
Alcohol N = 22,985 (44% age 65+) Deaths: 990 / 5,393	Non-Heavy Drinkers	1.00	1.00
	Heavy Drinkers	1.74	1.42

Notes: Body mass index (BMI) was based on measured weight and height and categorized according to the World Health Organization criteria, as described in note for Figure 1d. Current smokers were those who had smoked at least 100 cigarettes in their lifetime and smoked now. Heavy alcohol use was defined as 15+ drinks/week for men and 8+ drinks/week for women. Separate regression models were fit for deaths that occurred before and at/after age 65. Deaths among those under age 65 were left censored in the first model, and deaths among age 65+ were right censored in the second. (The SAS entry= option was used with proc phreg) Fifty percent of the sample in our analyses attained age 65 or greater. Those lost to follow-up were assigned a survival time of ½ the possible survival interval before the time when they were lost, but were censored on mortality. Models also included race: white (including Hispanic), black, and other, and age in 5-year age groups (coefficients not shown). These analyses omit those under age 25 and those who died within the first 4 years of follow-up. BMI analyses excluded those who were underweight at baseline because this can be indicative of pre-existing illness.[42] Analyses used the Naitonal Health and Nutrition Examination Surveys I, II, and III, linked to the National Death Index (NDI).

Table 4: Effects on Health-Related Quality of Life of Smoking, Body-Mass Index, and Heavy Alcohol Use

	Mean predicted Health-Related Quality of Life (HRQOL) Score
Normal weight	0.85
Overweight	0.82
Obese	0.79
Morbid obese	0.74
Nonmokers	0.85
Current smokers	0.77
Non-Heavy Drinkers	0.828
Heavy Drinkers	0.825

Notes: The effects of body mass index (BMI) and smoking were assessed in the 2002 Medical Expenditure Panel Survey (MEPS) and the effect of heavy drinking was assessed in the 2010 National Health Interview Survey (NHIS). BMI was based on self-reported weight and height and categorized according to the World Health Organization criteria, as described in note for Figure 1d. Smokers were those reporting that they currently smoked. Heavy alcohol use was defined as 15+ drinks/week for men and 8+ drinks/week for women.

separates factors into those that improved and those that worsened and ranks them by the magnitude of these effects. Reduced smoking has had the largest effect, improving life expectancy by 1.26 years and QALE by 1.42 years. Reductions in motor vehicle fatalities affected fewer individuals but also had an important effect of improving population life expectancy, by 0.43 years. To put the magnitude of these improvements in context, the total life expectancy improvement at age 18 over the past half-century was about 7 years; we do not have a comparable QALE estimate because quality of life data are not available for 1960. In terms of life expectancy, therefore, the factors that improved LE accounted for 25% of the total. Valuing the total effect of the factors that improved in dollars, the QALE gain is over $65,000 per person over the course of his or her adult life.

Table 5: Change in Life Expectancy and Quality Adjusted Life Expectancy at Age 25 Attributable to Behavioral Risk Factors Between 1960 and 2010

	Change (years)		Value of Improvement	
Risk Factor	LE	QALE		
Overall	6.9			
Areas of Improving Health:				
Smoking	1.26	1.42	$32,495	$52,011
Motor Vehicle Accidents*	0.43	0.34†	$15,241	$12,450
Alcohol‡	0.06	0.05	$1,065	$967
Total	**1.75**	**1.82**	**$48,801**	**$65,428**
Areas of Declining Health:				
Obesity	-1.00	-1.53	-$23,685	-$57,950
Poisoning*	-0.26	-0.21†	-$8,811	-$7,171
Firearms	-0.03	-0.03†	-$1,677	-$1,401
Total	**-1.30**	**-1.77**	**-$34,173**	**-$66,522**

*Excluding 25% of improvement assumed to be attributable to improvements in medical care.

†Assuming no change in QOL; QALE change reflects only the LE change.

‡Alcohol measured from 1973-2010.

Note: LE = life expectancy; QALE = quality-adjusted life expectancy; QOL = quality of life

Of the factors that worsened, obesity had the largest effect, reducing LE by one year and QALE by over a year and a half. Increases in accidental poisoning deaths held back LE improvement by over a quarter of a year. Accounting for the contribution of medical advances to improved survival of poisoning victims over time means that poisoning events occurred even more frequently than the mortality data indicate. In this case because the effect of behavioral change

for poisoning was negative, we accounted for the improvement in medical care by increasing the behavioral effect to 125%. Firearm suicide and homicides, which worsened slightly overall, held back LE by a small amount, 0.03 years. The total dollar value associated with QALE not gained due to the three worsening factors combined was about $64,000; only slightly less than the $65,000 gained from factors that improved.

The results of our sensitivity analyses on the proportion of mortality improvement attributable to medical care are shown in Table 6. Whether medical care accounts for as little as 10% or as much as 50% of the improvement, the remaining improvement in motor vehicle mortality attributable to public health and behavioral change remains large, accounting for a gain in life expectancy between one-half and one-third of a year from 1960 to 2010. For poisoning deaths, the extent of the public health problem varied little with the magnitude of the assumed medical benefit; poisoning held back LE improvement by between 0.23 and 0.31 year, depending on the extent to which medical care may have prevented additional overdose deaths. The total net effect of public health and behavioral change on life expectancy for all six factors was estimated to vary between 0.57 and 0.25 year depending on the assumed effect of medical care in preventing motor vehicle and poisoning deaths.

Table 6: Sensitivity Analyses on the Proportion of Change in Life Expectancy at Age 25 Due to Medical Care Improvement Between 1960 and 2010

Risk Factor	Life Expectancy Improvement		
	Point Estimate 25%	Lower Bound 10%	Upper Bound 50%
Motor Vehicle Accidents	0.43	0.52	0.29
Poisoning	-0.26	-0.23	-0.31
Total net effect of all six factors	0.45	0.57	0.25

Note: For motor vehicle deaths, we model results assuming that a portion of the observed mortality improvement (25%, 10%, and 50%) was due to medical care. For poisoning deaths, we assume that mortality would have worsened even more than observed if not for the effect of medical care; thus we model an increase in the effect of behavioral change and public health interventions (125%, 110%, and 150%). Last row shows the net effect on life expectancy change of all six risk factors we considered.

Impact of Reversing Trends

Table 7 shows the results of simulated improvements for obesity, poisoning, and firearm suicide/homicide. These were hypothetical scenarios in which we modeled the effect of progress that might be possible if public health and behavioral changes could be achieved in these areas at levels similar to those seen with smoking or motor vehicle accidents. We did not assume that we could completely reverse the negative factors, returning the population to 1960 rates, since this would be unrealistic; looking back at the dramatic reduction in smoking, it was far from completely eliminated. Rather, it was reduced by about half. Thus, we chose to model a 50% decline in morbid obesity (and a corresponding increase in normal weight), since morbid obesity was the major driver of ill effects of high BMI. Similarly, we modeled a 50% reduction in accidental poisoning (primarily drug overdose) deaths.

In estimating what would be a comparable rate of progress for firearm fatalities, we considered firearm safety as approximately equivalent to convincing people to wear a seat belt. The literature on motor vehicle interventions estimates that primary seat belt laws (allowing ticketing for not wearing a seat belt with no other traffic offense) resulted in about a 10% reduction in motor vehicle deaths.[39] We thus modeled the effect of a hypothetical firearm intervention with a similar impact. The positive effect on overall life expectancy was fairly small, primarily because firearm morality had already declined since its peak in the 1980s and 1990s.

As Table 7 shows, these simulated improvements yielded 0.92 years of improved life expectancy together and 1.09 years of increased quality-adjusted life expectancy. These are substantial. For

Table 7: Effects of Hypothetical Reductions in 2010 Mortality Rates from Obesity, Poisoning, and Firearms

Risk Factor	Improvement in 2010 vs actual LE	QALE	Scenario	
Obesity	0.76	0.96	50% reduction in morbid obesity	} (comparable to smoking decline)
Poisoning	0.14	0.11*	50% reduction in deaths	
Firearms	0.03	0.02*	10% reduction in deaths	(comparable to seat-belt use)
Total	**0.92**	**1.09**		

* Assuming no change in QOL; QALE change reflects only the LE change.

example, the gain from reducing obesity would be over half of the gain from reduced smoking since 1960. The gain in reduced poisoning deaths would be about one-third of the gain from reduced motor vehicle deaths since 1960.

Discussion

Declines in just two factors--smoking and motor vehicle accident deaths--account for a substantial portion (one-quarter) of the improvement in population quality-adjusted life expectancy over the past half-century, demonstrating the important impact of behavior change and public health interventions. Though the mortality decline from reduced smoking is well known, we also quantify the effect of this decline on nonfatal health.

Of the other factors that we consider, slight reductions in heavy alcohol use also had a small positive effect, while slight increases in firearm suicide and homicide had a negative effect on population health. Substantially holding back population QALE improvement over the past 50 years were increases in obesity and drug overdose deaths. Our simulations indicate the extent of improvement that could be achieved with effective public health interventions to address the worrisome trends in these harmful factors, if we can repeat in these areas the success we've had in others. Our simulation suggests that progress on obesity and accidental poisoning comparable to that made on smoking in the past half century would have an effect on health almost three fourths the size of the large (1.26 year) effect of the reduction in smoking on life expectancy.

Implications for Practice

Following the examples of the various effective interventions in the areas of tobacco,[7] motor vehicle accidents,[39] and child poisoning,[19] Hemenway and colleagues[13,14] have proposed many analogous ways in which similar progress could be made in reducing firearm deaths, including regulation, taxation, safety training, and identification and counseling of at-risk individuals. In the case of accidental poisoning, rapidly growing abuse of prescription medications, which is also known to serve as a gateway to the use of illegal drugs, is currently gaining widespread attention, garnering efforts to better understand and address the problem, in part by detecting and reducing over-prescription of the most problematic medications.[25,46,49] The recent increases in

alcohol poisoning deaths underline the importance of increased efforts to reduce binge drinking and discourage the mixing of alcohol with energy drinks.[48]

Prevention of obesity, particularly among children, has been a key focus in recent years, but it has been difficult to combat the roots of obesity, including sedentary lifestyles, insufficient physical activity, widespread availability of high-calorie food in large portions, and reduced time available for food preparation in the home[50,51,52,53,54] Those with low incomes face unique challenges in adopting healthful behaviors, including reduced or inconsistent access to affordable healthy food of good quality, greater availability of fast food restaurants, reduced physical activity resources, reduced access to quality health care, and greater exposure to advertising of obesity-promoting products.[55] Continued efforts to address these problems will be essential in order to reduce death and disability resulting from high BMI.

Among those already obese, the clinical efficacy of a number of weight loss interventions has been demonstrated[56] and there is encouraging evidence that even modest weight loss can have important impacts on public health.[56] The challenge is to increase the use of these interventions, as well as providing ongoing support to help individuals maintain weight loss in the long-term. Complementary interventions include those affecting food consumption (e.g. nutrition labeling, taxation and subsidy of specific foods[57] or nutrients[58]) and increasing access to healthy foods and exercise opportunities within communities.[59]

Alcohol use can also be reduced through taxation, and restrictions on alcohol availability.[60] However, in order to further combat the effects of heavy and binge drinking, these strategies must be combined with others that are known to be effective, including information dissemination, early intervention by primary physicians, and behavioral and pharmacological interventions to treat alcohol dependence.[60]

Finally, continued progress is crucial in the areas where we have seen success; increasing the use of proven methods to prevent youth smoking and achieve smoking cessation,[31] and broadening the adoption of laws and practices that improve the safety of vehicles, roads, drivers, passengers, pedestrians, and those riding bicycles.[12] Measures to address the safety of older drivers and

pedestrians will be increasingly important as the population ages.[12] Promising new technological interventions to save lives in motor vehicle accidents include features to help first responders more quickly access vital information, such as Google Glass,[61] vehicles with the ability to automatically contact emergency workers in the case of a collision, and quick response (QR) codes that provide internal vehicle diagrams to emergency rescue workers.[62]

Implications for Research

Our findings underline the importance of research to understand the roots of behavioral health problems and develop successful interventions and implementation strategies. The dramatic lifesaving effect of prior research is demonstrated most poignantly for smoking and motor vehicle fatalities.[7, 39] The skyrocketing rates of poisoning deaths, driven in particular by prescription drug overdose, point to an urgent need for research on the prevention and treatment of prescription drug addiction. Additional research on the impact of firearm interventions, which has lagged behind research on other behavioral causes of death, will also be critical to addressing this social problem. Finally, continued research is required to understand specific pathways to the development of obesity, heavy alcohol use, and binge drinking habits, and to test the most effective ways to broaden the use of strategies already known to be effective in reducing the harms of all of these behavioral risk factors.

Limitations

Our study has some limitations. While it quantifies the effects of some major causes of mortality and morbidity, it does not account for the many other factors that determine life expectancy and HRQOL, such as genetics, environmental toxins, and stress. Also, the impact of different BMI levels on mortality is a matter of ongoing debate.[63] However, we have calculated our relative risks of mortality directly in nationally representative data and have found our past results to be robust to sensitivity analyses using other published relative risks.[3,42,64]

We measured HRQOL associated with obesity, smoking, and heavy alcohol use at a single point in time, since quality-of-life data were not available over our extended time period of analysis. While we would not expect the ill-effects of these behaviors to change nearly as rapidly as their prevalence, the morbidity associated with them may have been worsened or improved by various

factors, including intensity of smoking and alcohol use, diet quality and activity level, and improved medical treatment of diseases associated with behavioral risk factors.[11,65,66]

Finally, our study uses the period life table approach, which assumes that as cohorts age, the distribution of their risk factors will change to reflect the distribution among people currently living at these older ages. However in the case of BMI, though obesity prevalence may be stabilizing[50,67] population BMI levels will rise with the aging of current younger cohorts, among whom obesity rates are (or were recently) at a historical high.[67] The effects of obesity on health occur primarily via disease, and the prevalence of diabetes in particular is at an all-time high and continues to increase. Our prior work forecasting alternate future scenarios concluded that the obesity increases would outweigh the benefits of smoking declines.[3] This is where medical care can have an important effect; an encouraging finding is the improved control of cardiovascular risk factors such as high cholesterol and hypertension, particularly among those who are overweight and obese.[65] More recently, a sharp decrease in complications has been found among those with diabetes.[66] Improved treatment of obesity-related diseases is thus vital to improving the Nation's health.

Conclusion

The benefits of behavioral and public health advances, where they have occurred, have been large; nearly 2 additional years of life primarily from improvements in just two main factors—smoking and motor vehicle accidents. In addition to reduced mortality, this accounts for quality of life improvements due to reduced smoking. However, these improvements are counterbalanced by declines in health due to other factors, primarily obesity and accidental drug overdose. These are fairly untapped areas in which progress could provide significant benefits, but they have proven more difficult to address. Our study demonstrates the enormous benefit of public health and behavioral change in improving population health, underscoring the importance of continued advances in these areas of research and practice.

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