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State Quality-Adjusted Life Expectancy for U.S. adults from 1993 to 2008

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Abstract

Purpose Quality-Adjusted Life Expectancy (QALE) is a summary measure of mortality and health-related quality of life (HRQOL) across different stages of life. This study developed a method to calculate state-level QALE for U.S. adults.

Methods Population HRQOL data came from the Behavioral Risk Factor Surveillance System (BRFSS). Using age-specific deaths from the Mortality Summary File, this study constructed life tables to estimate life expectancy and QALE for all 50 States and the District of Columbia by sex and race from 1993 through 2008.

Results From 1993 to 2008, the QALE of an U.S. adult at 18 years old had increased from 51.2 to 52.3 years. In 2006, states with the highest QALE were Hawaii (56.2), Minnesota (55.2), North Dakota (54.9), Iowa (54.7), and Nebraska (54.4), while the states with the lowest QALE were West Virginia (47.1), Mississippi (48.2), Alabama (48.5), Kentucky (48.5), and Oklahoma (49.0).

Conclusions Because population HRQOL values and mortality statistics are available from existing and publicly accessible data and because formulas for the calculation of QALE and its standard error are easy to incorporate in a spreadsheet, State and local Health Departments can calculate QALE as a routine surveillance measurement for tracking their population's health over time.

Keywords Health-Related Quality of Life (HRQOL) · Life expectancy · Quality-Adjusted Life Expectancy (QALE) · Mortality · Morbidity

Abbreviations

QALE	Quality-Adjusted Life Expectancy
HRQOL	Health-Related Quality of Life
QALYs	Quality-Adjusted Life Years
CDC	The U.S. Centers for Disease Control and Prevention
NCHS	The National Center for Health Statistics
BRFSS	The Behavioral Risk Factor Surveillance System
MEPS	The Medical Expenditure Panel Survey

Introduction

The U.S. Centers for Disease Control and Prevention (CDC) and the State and local Health Departments routinely collect and use both morbidity and mortality data such as cases and deaths from diseases and/or conditions for the tracking the health of their populations and analyzing the burden of disease and the degree to which risk can be prevented or reduced [1, 2]. However, as noted by the Secretary's Advisory Committee on National Health Promotion and Disease Prevention, a single measure such as the Quality-Adjusted Life Expectancy (QALE) would be particularly useful in quantifying the overall health impact

The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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of risk factors associated with both morbidity and mortality using one number [3]. Such a measure summarizes the overall health for the population and provides comparisons among local regions as well as monitors changes over the time [4].

Life expectancy is a summary measure of the age-specific mortality rates in a population [5, 6]. Health-related quality of life (HRQOL) assesses a person's perception of her/his health. Since HRQOL differs across different stages of life, calculating life expectancy adjusted by HRQOL would provide a more complete measure for assessing overall health [4, 7]. Besides personal perceptions, preference-based measurements of HRQOL assess how much a person values one health state vs. another state using a summary score (also called a utility value) [4]. For example, the EuroQoL Group's EQ-5D health state preference instrument uses three levels of five health dimensions—mobility, self-care, usual activities, pain or discomfort, and anxiety or depression—to distinguish 243 health states, each with its own utility. Preference-based HRQOL measures are anchored at 0 (dead) and 1 (perfect health) [7, 8]. The QALE combines utilities from such preference-based measurements with life expectancy to yield a summary score in expected years of life [7]. Thus, 1 year of life lived at a utility value of 0.8 is equal to 0.8 Quality-Adjusted Life Years (QALYs), and the QALE at age x is the total QALYs through the remainder of expected life (i.e., from age x to the life expectancy) [4, 5, 8].

To date, the QALE has not been used as a health surveillance measurement in the United States because preference-based HRQOL data are not routinely collected at the national, State, or local levels. In April 2008, an expert panel reviewed the CDC HRQOL Team's activities and provided guidance for improving the use and the usefulness of HRQOL surveillance in public health [9]. One panel suggestion was to "develop and disseminate methodology for calculating health-related quality of life–adjusted life expectancy for public health practitioners at the county and state levels who have limited resources for such analyses." Because more than 3,100 U.S. counties exist and because many less populous counties each year have too few survey respondents for QALE estimation, this study will focus on only the 50 States and the District of Columbia.

The main objective of this study is to develop and apply a methodology to calculate QALE at the national and State levels using currently available legacy data. Specifically, this study estimated QALEs and their standard errors for adults aged 18 years and older from 1993 to 2008 and for all fifty U.S. states and the District of Columbia. This study also provided such estimates by sex and for blacks and whites in States with sufficient sample sizes and compared these healthy life expectancies among the States.

Materials and methods

HRQOL data: Population HRQOL data were from the 1993 to 2008 Behavioral Risk Factor Surveillance System (BRFSS), an ongoing state-based survey of representative samples of non-institutionalized civilian adult residents (18 years and older) from each of the fifty states and the District of Columbia [10, 11]. The BRFSS was designed to monitor population health status and risky health behaviors associated with premature death at the State level and to identify trends over time [10, 11]. Annual sample sizes ranged from 102,263 in 1993 to 406,749 in 2008, and the total sample size used in this analysis was 3,590,540.

The BRFSS includes four questions (HR-QOL4) that asked respondents to report their general health status (excellent, very good, good, fair, or poor) and the numbers of their physically unhealthy days, mentally unhealthy days, and days with activity limitation during the past 30 days [12]. However, because these questions are not preference-based measures of HRQOL, they cannot be used to calculate QALYs directly [8, 9, 13]. Recognizing this limitation, the HRQOL Surveillance Expert Panel convened by the CDC's HRQOL Team suggested calibrating HR-QOL4 measures to preference-based HRQOL scores [9]. Two published studies had examined the possibility of a statistical crosswalk between the HR-QOL4 questions and health utility values and had derived multivariable conversion formulas for estimating utility values from these questions [14, 15]. This analysis used results from a previously constructed algorithm to obtain values from the EQ-5D a preference-based HRQOL measure for respondents in the BRFSS, based on their age and answers to the HR-QOL4 questions [14]. For example, for those 18-24 years old who reported 0 days for each of the three unhealthy days questions and reported "excellent" general health, the estimated EQ-5D index is 0.997. Because the fit was not exact between the observed EQ-5D values and the EQ-5D index estimated from age and the answers to the HR-QOL4 questions, QALEs calculated from observed EQ-5D values would differ from those calculated from these EQ-5D estimates. However, the authors believe these differences would be small. Moreover, because different health preference measures yield broadly similar mean utility values across population subgroups [14–16], QALEs estimated from these different measures, though not tested here, would probably also be very similar because the health preference measures are closely correlated and indicate one underlying "health" factor [17].

Death and population data: The National Center for Health Statistics (NCHS) has prepared the summary statistics of U.S. deaths (accessible at http://wonder.cdc.gov/mortSQL.html). State-level age-specific deaths for recent years (the most recent year is 2006) are available by sex and race. Age-specific death rates were obtained by dividing numbers of deaths by census and intercensal population estimates prepared by the US Census Bureau (available till 2008 and accessible at www.census.gov/popest/states/asrh/).

Life expectancy and QALE: To illustrate the calculation of life expectancy and QALE, let d_i and N_i be the deaths and populations for age i to $i+1$ years. The observed age-specific death rate is $m_i = d_i/N_i$, and the probability of dying in one year (i.e., mortality rate) is $q_i = 1 - e^{-m_i}$ [5, 6, 18]. Let A_0 be a hypothetical population of 100,000 at the first age interval (i.e., 18 years) and A_i be the number of the population surviving to age i ($i \geq 18$). Assuming that those who died during a 1-year interval lived an average ½ years, the Life Years between age i and $i+1$, D_i, is $(1 - q_i/2)A_i$. For those in the last age interval (i.e., aged 85+), the total life years is approximately $D_{85} = A_{85}/m_{85}$ by assuming an exponential distribution of survival time [19]. The life expectancy at age x is the total Life Years above age x divided by the population surviving to age x or

$$\mathrm{LE}_i = \frac{\sum_{i \geq x} D_i}{A_i} \quad (1)$$

Suppose that y_i is the average HRQOL utility score (EQ-5D index) at age i; then, the quality-adjusted life years between age i and $i+1$ is $D_i y_i$ [4, 7, 8]. Therefore, the QALE at age x is

$$\mathrm{QALE}_i = \frac{\sum_{i \geq x} D_i y_i}{A_i} \quad (2)$$

Applying the delta method and assuming $\mathrm{COV}(m_i, m_j) = 0$ and $\mathrm{COV}(y_i, y_j) = 0$ if $i \neq j$ and $\mathrm{COV}(m_i, y_j) = 0$ for all i, j [5, 6, 19], the variance of the estimated QALE is approximately:

$$\begin{aligned}\mathrm{VAR}(\mathrm{QALE}_x) &= \sum \left[\left(\frac{\partial \mathrm{QALE}_x}{\partial q_i} \right)^2 \mathrm{VAR}(q_i) + \left(\frac{\partial \mathrm{QALE}_x}{\partial y_i} \right)^2 \mathrm{VAR}(y_i) \right] \\ &= \frac{\sum_{i=x}^{84} \left[A_i^2 \left(\frac{y_i}{2} + \mathrm{QALE}_{i+1} \right)^2 \mathrm{VAR}(q_i) + A_i^2 \left(1 - \frac{q_i}{2}\right)^2 \mathrm{VAR}(y_i) \right]}{A_x^2} \\ &\quad + \frac{\mathrm{VAR}(L_{85}) y_{85}^2 + D_{85}^2 \mathrm{VAR}(y_{85}) + \mathrm{VAR}(L_{85}) \mathrm{VAR}(y_{85})}{A_x^2}\end{aligned} \quad (3)$$

where $\mathrm{VAR}(q_i) = q_i^2(1 - q_i)/d_i$ for age <85 and $\mathrm{VAR}(L_{85}) = \frac{\left(e^{-\sum_{k<85} m_k}\right)^2}{d_{85} m_{85}^2} A_{18}^2$. $\mathrm{VAR}(y_i)$ are the variances of q_i and of the mean y_i, respectively.

Estimates for small states: The estimated life expectancy and QALE in some small states and some small demographic subgroups can be unreliable because of (1) few or no deaths in a particular age category; and/or (2) insufficient data in the BRFSS samples to make reliable estimates of the mean EQ-5D scores in some age categories.

According to the NCHS, the estimated death rate is unreliable if the number of deaths is fewer than 20 [18]. For those age groups in which the number of deaths was fewer than 20, we aggregated data into a larger age interval and used a 3-year moving average to obtain more reliable estimates of deaths and death rates. If no death was reported in a 10-year age interval for 3 consecutive years or if the expected death in a single-year age interval was less than 0.1 per year, we did not provide an estimate of life expectancy for this state. Since 2007 and 2008 death data were not available, we provided predictions for these 2 years through a time-series autoregressive moving average model (ARMA) from the 1993 to 2006 data [20]. For the 2007 and 2008 model predictions, the variance of estimated age-specific mortality, q_i, should be adjusted for the uncertainty of these predictions:

$$\mathrm{VAR}(q_i) = \frac{q_i^2(1 - q_i)}{d_i} + (1 - q_i)^2 \mathrm{VAR}(\hat{m}_i) \quad (4)$$

where $\mathrm{VAR}(\hat{m}_i)$ was the variance of model-based estimates of death rate.

To obtain reliable estimates of the mean EQ-5D score (i.e., y_i in Eqs. 2, 3) from the BRFSS, a reasonably large sample size was required. Because the complete life table (in single-year age intervals) constructed the QALE calculation and the uncertainty of EQ-5D estimates from each one-year age interval contributed very little to the total variance of estimated QALE, a sample size $n > 10$ was considered adequate for this analysis. For ages with smaller sample sizes, we aggregated the data into a larger age category and used a 3-year moving average to provide more reliable estimates [8]. If the combined sample size was fewer than 10 for a 10-year age interval over 3 years, we did not provide estimates of QALE for the state. Also, since we used the estimated EQ-5D values for the BRFSS data instead of observed EQ-5D values, we adjusted the uncertainty of the estimated EQ-5D by

$$\mathrm{VAR}(y_i) = \mathrm{VAR}(\bar{y}_i) + \mathrm{MSE}(y)/n_i, \quad (5)$$

where $\mathrm{VAR}(\bar{y}_i)$ is the variance of estimated mean EQ-5D index from the BRFSS and $\mathrm{MSE}(y)$, the mean squared error of the mapping algorithm developed previously. The value of $\mathrm{MSE}(y)$ was $0.106^2 = 0.011236$ for the algorithm we used in this study and n_i is the sample size [15].

Results

In 2006, life expectancy for an 18 year old U.S. adult was 61.1 years (SE = 0.004 years), and the QALE for the same individual was 52.3 years (SE = 0.04 years). Figure 1 shows the trend of life expectancy and QALE for US adults at 18 years old from 1993 to 2008 by the four sex-by-race subgroups (estimates of life expectancy for ages older than 18 years are available upon request). During this 16-year interval, white women had the longest life expectancy (63.8 years in 2008; Fig. 1a); black women, the next longest (60.7 years); then white men (58.9 years); and black men, the shortest life expectancy (53.5 years). Although QALE was strongly related to life expectancy (average $r = 0.840$ for the same age, race, and sex), the order of QALE in these four sex-by-race subgroups differed from that for life expectancy (Fig. 1b): White women (54.1 years in 2008) > white men (51.1 years) > black women (50.5 years) > black men (46.1 years).

Although both life expectancy and QALE increased progressively from 1993 to 2008, the increases in the QALE were much smaller than the increases of life expectancy in all four sex-by-race subgroups, probably due to the fact that HRQOL scores decreased during the same time period (data not shown, but reported previously) [21]. Of the four sex-by-race subgroups, black men had the largest increases in both life expectancy and QALE, which increased 10.1 and 8.1% respectively across the 16-year interval. White men and black women had similar increases for both life expectancy (5.1 and 5.4%, respectively) and QALE (3.0 and 3.3%, respectively). White women had the smallest increases in these two measures (2.3 and 0.4%, respectively).

QALE differed statistically significantly at the state level (Fig. 2). For example, at 18 years old in 2006, the most recent year that death data were available, the Appalachian and Mississippi Delta states had the lowest QALE, while the West North Central States had the highest QALE. States with the highest QALE were Hawaii (56.2), Minnesota (55.2), North Dakota (54.9), Iowa (54.7), and Nebraska (54.4), while the states with the lowest QALE were West Virginia (47.1), Mississippi (48.2), Alabama (48.5), Kentucky (48.5), and Oklahoma (49.0). The range of state QALE, 9.1 years (from 47.1 to 56.2), exceeded the range of state life expectancy, 6.4 years (from 57.5 to 63.9).

Although the annual state-specific QALE has been calculated by gender and race from 1993 through 2008 (available on request), only results for 3 years—1993, 2006, and 2008—and the percentage changes from 1993 to 2006 are reported here (Tables 1 and 2). The overall percentage increase in QALE from 1993 to 2006 for men was 4.0%. The District of Columbia had the biggest increase in QALE among men (+13.5%), but in two states (Alabama and Oklahoma), QALE decreased more than 2% among men. For women, the overall QALE were relatively stable during this period (+0.5%), but at the state level, the percentage changes in QALE ranged from a decrease of −5.7% in Oklahoma to an increase of +3.7% in New York.

Blacks had a larger percentage increase in QALE (+5.4%) from 1993 to 2006 than whites (+1.6%). For individual states, the QALE among blacks increased the most in Rhode Island, New Jersey, New York, and Florida but decreased more than 3% in three states: West Virginia, Oklahoma, and Alabama. Among whites, states with the biggest QALE increases were New York, Minnesota, North Dakota, Vermont, and Massachusetts, and states with the biggest QALE decreases were Oklahoma, Alabama, West Virginia, and Mississippi.

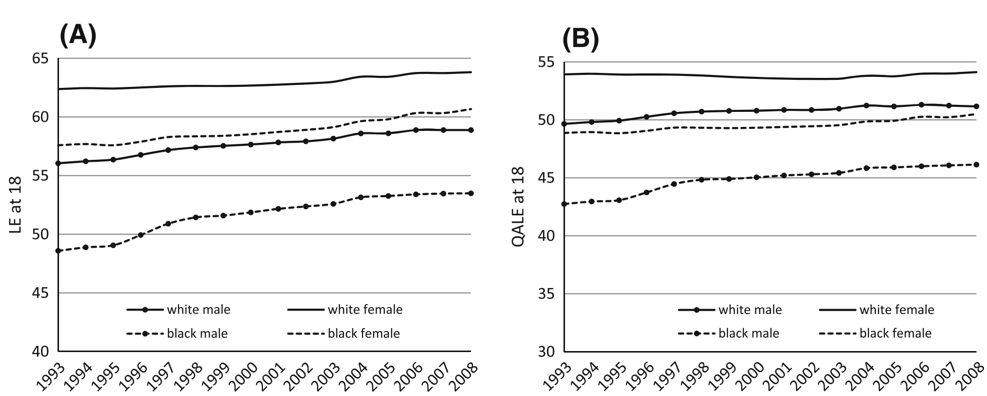

Fig. 1 Life expectancy (**a**) and QALE (**b**) at 18 years old for U.S. adults by sex and race, from 1993 to 2008

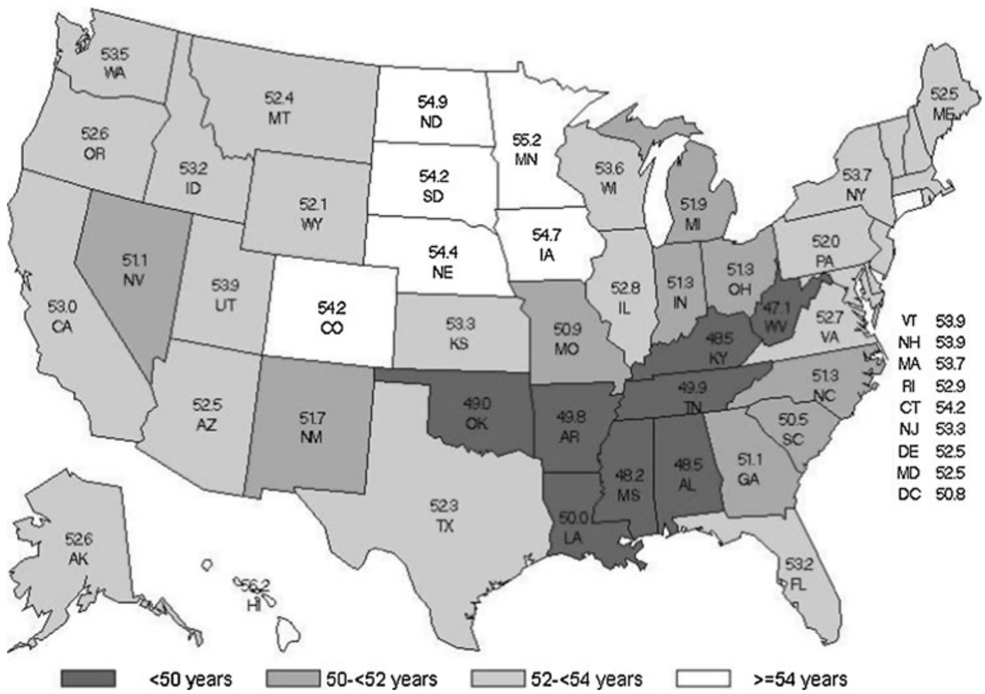

Fig. 2 QALE at 18 years older for total U.S. adults in 2006

The reliability of life expectancy and QALE estimates was examined and reported in Table 3. Of the 126 sets of life expectancy estimates at 18 years old for the whole U.S. from 1993 to 2006 (14 years by 3 sex categories [both, male, female] by 3 race categories [both, white, black]), the standard errors were all less than 0.02 years, with an average standard error less than 0.01 years. The standard errors of the QALE for the same groups were much larger but still very precise (all less than 0.3 years). At the state level, as expected, these standard errors were larger than those at the national level. However, 99.5% of the 2,142 estimated standard errors were less than 0.5 years for the QALE estimates of combined races. When calculated separately by race (white and black), a larger proportion of these state estimates (mostly among blacks) were either unavailable (due to the small number of deaths or the small number of BRFSS respondents) or unreliable with large standard errors ($\geq$0.5 years). Of the 4,284 possible state-level estimates by race (14 years by 51 states by 3 sex categories by 2 race categories), 670 (15.6%) life expectancy estimates were unavailable and 30 (0.7%), unreliable (SE $>$ 0.5 years or margin of error $>$ 1 year). For QALE, 877 (20.5%) estimates were unavailable and 65 (1.5%) estimates were unreliable (SE $>$ 0.5 years). Ninety-four percent of these unavailable or unreliable estimates were among blacks. Nonetheless, for estimates among blacks, 69.3% of state-level life expectancy estimates and 58.5% of QALE estimates were reliable (SE $<$ 0.5 years).

Since 2007 and 2008 estimates used estimated death rates, the standard errors of both measures were larger than the standard errors of same estimates for the years when death data were available (i.e., 1993–2006). However, both life expectancy and QALE estimates were still reliable for national-level estimates and for state-level estimates of combined races. All life expectancy estimates and 99.3% QALE were reliable (SE $<$ 0.5 years). Of the 612 possible state-level estimates stratified by race, 81.7% of the life expectancy estimates and 69.6% of the QALE estimates were reliable.

Finally, sensitivity of the estimated QALE using EQ-5D scores obtained from the mapping algorithm and the Healthy Days Measures was examined. For the 2000–2003 cohort of the Medical Expenditure Panel Survey (MEPS), a nationally representative sample of adults ($N = 72{,}249$) were asked the EQ-5D questions. The sensitivity analysis compared the calculated QALEs using the observed EQ-5D data from the MEPS and the estimated EQ-5D data from the BRFSS (Table 4). In general, the differences were less than 1% between the two methods, and the mean absolute difference was 0.23 years.

Discussions

This paper reports the development of a method to calculate state-level QALE for U.S. adults using currently available data. Because the proposed method uses legacy data, i.e., the BRFSS and the Mortality Files, investigators are able to analyze the trend of QALE since 1993 and thus demonstrate that QALE can be used as a routine health

Table 1 State level QALE at 18 years old by sex for 1993, 2006, and 2008

State	Male							Female						
	1993		2006			2008		1993		2006			2008	
	QALE	SE	QALE	SE	% Change	QALE	SE	QALE	SE	QALE	SE	% Change	QALE	SE
United States	48.9	0.042	50.9	0.034	4.0	50.8	0.087	53.4	0.077	53.7	0.065	0.5	53.8	0.090
Alabama	47.6	0.202	46.6	0.173	−2.1	47.3	0.354	52.5	0.354	50.2	0.193	−4.4	50.3	0.299
Alaska	50.3	0.429	51.6	0.244	2.5	50.6	0.414	55.0	0.350	53.5	0.695	−2.7	52.7	0.546
Arizona	49.0	0.142	50.8	0.322	3.7	51.6	0.374	53.4	0.379	54.2	0.284	1.5	55.5	0.545
Arkansas	47.1	0.136	48.0	0.169	1.8	48.7	0.299	51.8	0.277	51.5	0.156	−0.5	51.4	0.276
California	49.4	0.144	51.9	0.174	5.0	51.8	0.348	53.1	0.325	54.1	0.504	1.9	54.9	0.365
Colorado	50.2	0.144	53.0	0.185	5.7	53.2	0.269	54.9	0.134	55.4	0.180	0.8	55.1	0.204
Connecticut	51.8	0.112	52.8	0.136	2.0	52.7	0.241	55.4	0.334	55.5	0.144	0.2	56.0	0.267
Delaware	49.1	0.099	51.2	0.267	4.4	50.9	0.322	52.5	0.341	53.7	0.262	2.3	53.3	0.328
District of Columbia	42.6	0.086	48.3	0.158	13.5	48.4	0.430	53.8	0.173	53.0	0.209	−1.4	52.9	0.374
Florida	49.0	0.170	51.5	0.143	5.1	51.6	0.198	53.7	0.387	54.9	0.161	2.3	55.0	0.227
Georgia	46.8	0.101	49.5	0.117	5.7	49.6	0.231	52.0	0.385	52.5	0.172	1.0	52.6	0.309
Hawaii	53.2	0.190	53.9	0.211	1.4	53.0	0.276	58.6	0.319	58.5	0.284	−0.1	57.8	0.435
Idaho	50.4	0.131	52.2	0.153	3.6	51.8	0.285	54.5	0.396	54.2	0.155	−0.5	54.2	0.277
Illinois	49.7	0.081	51.6	0.119	3.8	51.0	0.232	54.0	0.206	54.0	0.153	0.1	53.8	0.203
Indiana	48.6	0.112	50.0	0.109	3.0	50.1	0.245	51.4	0.312	52.6	0.162	2.2	53.1	0.308
Iowa	51.2	0.148	53.3	0.160	4.0	52.6	0.257	56.0	0.268	56.1	0.182	0.1	55.2	0.248
Kansas	51.0	0.097	52.0	0.123	1.9	52.0	0.204	55.5	0.321	54.4	0.138	−2.0	54.1	0.269
Kentucky	46.2	0.133	46.8	0.151	1.4	47.1	0.273	51.1	0.281	50.2	0.179	−1.6	50.0	0.270
Louisiana	46.6	0.079	47.9	0.117	2.7	47.6	0.240	52.2	0.293	52.1	0.149	−0.3	51.5	0.237
Maine	50.0	0.133	50.7	0.226	1.5	51.0	0.294	55.1	0.209	54.1	0.216	−1.9	54.4	0.324
Maryland	48.9	0.213	50.9	0.138	4.0	51.3	0.260	53.7	0.193	54.0	0.139	0.5	54.0	0.210
Massachusetts	49.9	0.115	52.2	0.092	4.6	52.4	0.221	54.2	0.207	55.1	0.129	1.8	55.2	0.202
Michigan	49.2	0.083	50.7	0.127	3.0	50.8	0.192	53.0	0.388	53.1	0.190	0.2	53.2	0.321
Minnesota	50.9	0.143	53.8	0.170	5.7	53.5	0.298	55.1	0.317	56.5	0.238	2.6	56.0	0.335
Mississippi	45.9	0.127	46.4	0.171	1.1	46.9	0.250	51.8	0.647	49.9	0.147	−3.6	50.5	0.265
Missouri	48.6	0.108	49.4	0.150	1.6	49.3	0.251	53.0	0.351	52.4	0.157	−1.1	52.6	0.297
Montana	49.0	0.118	51.0	0.155	4.0	51.3	0.292	53.5	0.338	53.8	0.152	0.6	54.1	0.280
Nebraska	50.5	0.137	52.8	0.132	4.5	52.6	0.265	55.6	0.215	55.8	0.134	0.5	55.4	0.222
Nevada	47.3	0.105	50.2	0.141	6.0	49.7	0.336	51.5	0.344	52.0	0.285	1.0	52.0	0.452
New Hampshire	50.9	0.128	52.6	0.140	3.3	52.4	0.277	55.0	0.197	55.1	0.187	0.2	54.8	0.333
New Jersey	49.8	0.071	52.0	0.123	4.5	51.6	0.248	53.5	0.284	54.4	0.189	1.6	54.3	0.354
New Mexico	50.5	0.143	49.9	0.213	−1.2	49.4	0.294	54.5	0.320	53.4	0.217	−2.0	53.2	0.379
New York	47.9	0.154	52.0	0.312	8.5	52.6	0.345	53.3	0.250	55.3	0.194	3.7	55.2	0.287
North Carolina	48.5	0.078	49.8	0.096	2.6	49.5	0.201	53.6	0.353	52.6	0.186	−1.8	52.9	0.311
North Dakota	51.5	0.131	53.0	0.151	2.9	53.0	0.336	54.9	0.276	56.8	0.216	3.4	56.4	0.303
Ohio	49.4	0.115	49.8	0.173	0.7	50.0	0.192	53.5	0.311	52.6	0.207	−1.7	53.0	0.232
Oklahoma	48.6	0.099	47.6	0.107	−2.1	47.9	0.233	53.5	0.243	50.4	0.134	−5.7	51.0	0.216
Oregon	50.2	0.100	51.5	0.178	2.7	52.0	0.259	53.9	0.185	53.6	0.143	−0.4	54.3	0.226
Pennsylvania	49.0	0.112	50.4	0.105	2.8	50.2	0.201	52.9	0.357	53.5	0.170	1.2	53.7	0.272
Rhode Island	48.8	0.108	51.0	0.152	4.5	51.0	0.285	54.0	0.300	54.6	0.191	1.2	54.2	0.302
South Carolina	47.1	0.106	48.8	0.158	3.5	49.1	0.272	53.2	0.396	52.2	0.239	−1.9	52.8	0.445
South Dakota	51.3	0.116	52.5	0.124	2.4	52.2	0.299	56.3	0.217	55.9	0.155	−0.8	55.4	0.302
Tennessee	47.5	0.084	48.3	0.215	1.8	47.8	0.240	52.8	0.241	51.4	0.281	−2.7	50.7	0.292
Texas	48.4	0.117	51.1	0.117	5.6	50.6	0.240	53.8	0.257	53.4	0.154	−0.6	52.7	0.258
Utah	52.0	0.158	53.5	0.204	2.9	52.6	0.334	54.0	0.285	54.2	0.239	0.4	54.1	0.385

Table 1 continued

State	Male							Female						
	1993		2006			2008		1993		2006			2008	
	QALE	SE	QALE	SE	% Change	QALE	SE	QALE	SE	QALE	SE	% Change	QALE	SE
Vermont	49.9	0.114	52.4	0.192	5.2	52.1	0.332	54.2	0.194	55.3	0.158	2.0	55.0	0.298
Virginia	49.3	0.094	51.2	0.149	3.9	51.3	0.236	53.6	0.502	54.2	0.175	1.1	54.3	0.345
Washington	50.6	0.084	52.3	0.096	3.5	52.2	0.191	54.6	0.202	54.5	0.111	−0.1	54.3	0.200
West Virginia	46.4	0.097	45.6	0.101	−1.7	46.6	0.300	51.2	0.246	48.7	0.173	−5.0	50.1	0.286
Wisconsin	50.6	0.172	52.3	0.208	3.2	52.2	0.234	54.3	0.402	54.9	0.218	1.0	54.9	0.350
Wyoming	49.6	0.186	50.8	0.252	2.3	50.8	0.318	54.1	0.298	53.4	0.195	−1.4	53.7	0.359

Table 2 State level QALE at 18 years old for whites and blacks for 1993, 2006, and 2008

State	White							Black						
	1993		2006			2008		1993		2006			2008[a]	
	QALE	SE	QALE	SE	% Change	QALE	SE	QALE	SE	QALE	SE	% Change	QALE	SE
United States	51.8	0.051	52.7	0.044	1.6	52.6	0.074	45.9	0.115	48.3	0.080	5.4	48.3	0.144
Alabama	50.9	0.336	49.2	0.207	−3.4	49.4	0.353	47.3	0.180	45.8	0.146	−3.2	45.7	0.302
Alaska	53.8	0.424	53.3	0.490	−0.9	52.5	0.386	–	–	–	–	–	–	–
Arizona	51.3	0.378	52.5	0.190	2.4	53.6	0.329		–	47.8	0.751	–	45.0	1.693
Arkansas	50.3	0.200	50.4	0.130	0.2	50.7	0.224	44.3	0.156	45.4	0.171	2.5	44.4	0.406
California	51.3	0.201	52.7	0.289	2.7	53.0	0.260	44.0	0.221	47.4	0.198	7.8	47.7	0.483
Colorado	52.8	0.097	54.3	0.132	2.8	54.1	0.154	–	–	52.6	0.390	–	50.8	0.641
Connecticut	54.0	0.244	54.4	0.111	0.8	54.5	0.203	–	–	51.2	0.292	–	51.1	0.550
Delaware	51.4	0.233	53.0	0.209	3.0	52.7	0.287	46.6	0.225	49.8	0.282	6.9	48.1	0.501
District of Columbia	–	–	57.8	0.328	–	–	–	44.5	0.125	46.4	0.145	4.1	46.1	0.367
Florida	52.2	0.195	53.5	0.118	2.6	53.5	0.179	44.2	0.248	49.2	0.301	11.2	49.1	0.465
Georgia	50.5	0.284	51.9	0.165	2.7	51.9	0.297	46.1	0.201	48.8	0.148	5.9	48.5	0.351
Hawaii	54.8	0.276	55.4	0.197	1.0	54.3	0.318	–	–	–	–		–	–
Idaho	52.5	0.221	53.2	0.109	1.3	53.0	0.198	–	–	–	–		–	–
Illinois	53.0	0.173	53.6	0.114	1.1	53.0	0.194	44.6	0.154	47.6	0.201	6.8	47.5	0.349
Indiana	50.4	0.214	51.6	0.121	2.5	52.1	0.230	45.9	0.194	47.6	0.172	3.6	45.6	0.435
Iowa	53.7	0.175	54.8	0.130	1.9	54.1	0.195	50.5	0.326	50.6	0.337	0.2	46.4	0.675
Kansas	53.5	0.236	53.6	0.120	0.1	53.3	0.217	48.6	0.178	47.4	0.217	−2.5	46.8	0.460
Kentucky	48.7	0.188	48.6	0.110	−0.1	48.6	0.187	47.5	0.204	47.5	0.285	0.1	46.9	0.523
Louisiana	50.9	0.260	51.2	0.111	0.7	50.8	0.186	45.9	0.113	46.6	0.199	1.7	45.3	0.311
Maine	52.7	0.109	52.6	0.150	−0.3	52.9	0.208	–	–	–	–		–	–
Maryland	52.7	0.215	53.2	0.113	0.8	53.3	0.198	46.9	0.139	49.9	0.280	6.4	50.6	0.321
Massachusetts	52.1	0.239	53.8	0.106	3.2	53.9	0.192	–	–	50.5	0.294	–	51.5	0.557
Michigan	52.1	0.243	52.6	0.136	0.9	52.9	0.225	45.1	0.204	47.3	0.169	5.0	47.5	0.407
Minnesota	53.3	0.194	55.5	0.165	4.1	55.0	0.257	46.4	0.211	49.4	0.483	6.4	49.2	0.662
Mississippi	51.0	0.137	49.4	0.123	−3.2	49.7	0.212	44.8	0.220	45.8	0.195	2.1	46.2	0.305
Missouri	51.4	0.210	51.5	0.126	0.2	51.6	0.233	44.6	0.323	46.5	0.141	4.2	46.0	0.464
Montana	51.5	0.206	53.0	0.114	3.0	53.3	0.197	–	–	–	–		–	–
Nebraska	53.4	0.137	54.6	0.098	2.3	54.4	0.178	–	–	50.1	0.422	–	46.9	0.757
Nevada	49.2	0.149	50.8	0.148	3.2	50.6	0.260	–	–	48.9	0.467	–	43.8	0.901
New Hampshire	53.1	0.164	53.9	0.143	1.5	53.8	0.265	–	–	–	–		–	–
New Jersey	52.7	0.164	53.6	0.136	1.7	53.2	0.258	43.0	0.295	49.0	0.200	14.1	48.3	0.382

Table 2 continued

State	White							Black						
	1993		2006			2008		1993		2006			2008[a]	
	QALE	SE	QALE	SE	% Change	QALE	SE	QALE	SE	QALE	SE	% Change	QALE	SE
New Mexico	52.7	0.201	51.8	0.159	−1.7	51.3	0.273	–	–	52.8	0.730	–	–	–
New York	51.2	0.218	53.8	0.176	5.2	53.9	0.279	47.2	0.261	52.5	0.211	11.2	52.1	0.408
North Carolina	52.3	0.198	51.9	0.120	−0.7	51.8	0.211	46.7	0.233	48.2	0.119	3.1	48.4	0.309
North Dakota	53.4	0.198	55.5	0.135	3.9	55.3	0.196	–	–	–	–		–	–
Ohio	52.1	0.217	51.8	0.154	−0.6	52.0	0.188	47.7	0.168	47.1	0.151	−1.4	47.1	0.358
Oklahoma	51.2	0.152	49.4	0.093	−3.5	49.8	0.168	48.6	0.162	46.7	0.155	−3.9	45.0	0.433
Oregon	52.0	0.108	52.5	0.110	0.9	53.1	0.178	46.3	–	46.4	0.878	0.3	51.8	0.918
Pennsylvania	51.8	0.197	52.5	0.110	1.3	52.4	0.181	43.7	0.222	46.9	0.144	7.4	47.2	0.503
Rhode Island	51.9	0.185	52.9	0.143	1.9	52.7	0.232	42.4	–	51.2	0.466	20.7	49.4	0.735
South Carolina	51.7	0.237	51.7	0.155	0.1	52.1	0.281	46.2	0.181	47.1	0.132	2.0	48.0	0.326
South Dakota	54.5	0.123	55.1	0.098	1.1	54.7	0.189	–	–	–	–		–	–
Tennessee	50.8	0.136	50.1	0.176	−1.3	49.4	0.210	46.6	0.133	47.9	0.230	2.9	47.3	0.353
Texas	51.6	0.151	52.6	0.102	2.0	52.0	0.190	45.2	0.270	47.9	0.273	6.1	46.5	0.415
Utah	52.9	0.323	53.9	0.161	1.7	53.3	0.263	–	–	–	–	–	–	–
Vermont	52.1	0.116	54.0	0.121	3.6	53.7	0.209	–	–	–	–	–	–	–
Virginia	52.5	0.348	53.2	0.124	1.3	53.3	0.251	46.4	0.227	49.7	0.136	7.0	49.2	0.482
Washington	52.6	0.136	53.4	0.095	1.4	53.2	0.183	46.5	–	49.4	0.360	6.2	47.5	0.596
West Virginia	48.7	0.148	47.0	0.116	−3.4	48.2	0.215	50.7	0.144	46.8	0.262	−7.6	45.4	0.866
Wisconsin	52.9	0.224	54.1	0.160	2.2	54.1	0.236	45.8	–	45.5	0.252	−0.6	45.1	0.575
Wyoming	52.3	0.190	52.4	0.167	0.1	52.4	0.243	–	–	–	–		–	–

[a] Estimates for 2008 were available only if estimates from 2004 to 2006 were available

Table 3 Descriptive statistics of standard error of life expectancy and QALE estimates

	1993–2006						2007–2008					
	N	Mean	SD	Min	Max	% < 0.5	*N*	Mean	SD	Min	Max	% < 0.5
At national level, for total and by sex and race												
SE for LE18	126	0.0066	0.0039	0.0030	0.0177	100.0	18	0.0611	0.0263	0.0271	0.1277	100.0
SE for QALE18	126	0.0654	0.0435	0.0304	0.2919	100.0	18	0.1027	0.0508	0.0521	0.2328	100.0
At state level, for total and by sex												
SE for LE18	2142	0.0437	0.0335	0.0109	0.2824	100.0	306	0.1432	0.0695	0.0536	0.4440	100.0
SE for QALE18	2142	0.1741	0.0780	0.0459	0.7173	99.5	306	0.2499	0.0699	0.1155	0.5458	99.3
At state level, by race												
SE for LE18	3614	0.0869	0.1700	0.0111	5.7148	83.7	498	0.1762	0.1151	0.0459	0.5971	81.7
SE for QALE18	3407	0.2007	0.1391	0.0434	3.0679	78.0	494	0.3567	0.3258	0.1216	5.0162	69.6

LE18: life expectancy at 18 years old

QALE18: Quality-Adjusted Life Expectancy (QALE) at 18 years old

N number of estimates available. When examined by race at state level, some states may not have estimates due to small samples. For example, in Wyoming, we did not provide estimates for blacks

surveillance measure for tracking population health over time. Additionally, because the formulas for QALE and its standard error calculation can be incorporated into a spreadsheet, State and local Health Departments can easily obtain the QALE of their population using public accessible data. Microsoft-Excel[TM] spreadsheets of abridged and

Table 4 Comparison of estimated QALE using observed and estimated EQ-5D index scores

Year	Sex	QALE use observed EQ-5D[a]	QALE use estimated EQ-5D[b]	% Difference[c]
2000	All	51.4	51.8	0.82
2001	All	51.6	51.8	0.43
2002	All	51.9	51.8	−0.13
2003	All	52.1	51.9	−0.39
2000	Male	50.1	50.3	0.43
2001	Male	50.3	50.4	0.08
2002	Male	50.5	50.4	−0.34
2003	Male	50.7	50.5	−0.49
2000	Female	52.7	53.2	1.03
2001	Female	52.9	53.2	0.58
2002	Female	53.2	53.2	−0.08
2003	Female	53.5	53.2	−0.45
Mean		51.7	51.8	0.12
RMSE		0.27		
MAD		0.23		
R^2		0.075		

RMSE root of mean squared error, *MAD* mean relative absolute difference

[a] QALE is calculated using observed EQ-5D from the MEPS

[b] QALE is calculated using estimated EQ-5D from the BRFSS

[c] Related difference between two methods

complete life tables for the QALE estimation are available upon request.

The current analysis shows good reliability of annual QALE estimates at the national and state levels and for the most demographic subgroups. The proposed method also can be used to calculate QALE and to understand the risk factors and disease burdens in areas as small as counties. Since the BRFSS was designed to provide reliable state-level estimates and estimates for some substate areas, or annual and monthly estimates for larger geographic areas [22], QALE can be calculated for some substate areas such as populous counties or metropolitan statistical areas by applying small area estimation techniques or aggregating data over several years with a careful choice of age intervals for constructing abridged life tables [5, 6, 19, 22].

Because many interventions are implemented at the state and local levels, public health decision makers need tools that allow them to examine the overall health for the population [3, 8]. The most important use of QALE in routine health surveillance is to provide a summary measure of mortality and morbidity statistics that tracks quality and years of healthy life [3]. A single measurement of overall health like QALE is particularly useful for directly comparing regions (within or among states) where a given policy has been implemented [3, 4]. Additionally, QALE can be used both to measure the burden of disease (associated with a particular risk factor, determinant, disease, or injury) and to conduct cost-effectiveness analyses of alternative interventions to reduce the burden on health [8, 22, 23]. For example, this study provides a proof of concept to calculate the burden of disease due to various conditions (i.e., to calculate years of healthy life lost to a disease or a risk factor). Such an analysis can change public health practice, affecting the design of healthy communities and the targeting of subgroups [8, 23, 24]. It is possible that using the mapping algorithm of EQ-5D scores may introduce bias into the cost-effective estimates but methods also exist to reduce the potential bias as well as test the sensitivity of the estimates. The potential benefits of providing these types of cost-effectiveness estimates to national and state policy makers may outweigh the concerns regarding introducing small amounts of bias.

The standard error formula of QALE estimates was derived based on an approximation (i.e., delta method) that assumes that mortality is independent to HRQOL. However, such an assumption may not be true. For example, the mean HRQOL score would be negatively associated with mortality (i.e., the worse HRQOL score, the higher mortality rate). To evaluate the accuracy of this approximation, we applied a computationally intensive bootstrap method to obtain the standard errors of estimates without assuming this independence. The standard errors of estimates for the two estimation procedure were nearly identical ($r = 0.999$ for life expectancy and $r = 0.998$ for QALE), and the standard errors estimated by the delta method were slightly larger than the standard errors estimated by the bootstrap method, about 0.28 and 0.18% larger for life expectancy and QALE, respectively. So, violation of the independence assumption has very little impact on the accuracy of the standard error calculation, and the delta method actually slightly overestimates these standard errors.

For the life expectancy calculation, random errors in mortality estimation will not have a big impact on the reliability of estimates for the national or state-level estimates. However, random errors and biases in the HRQOL estimates (i.e., EQ-5D scores) could strongly affect the reliability of the QALE estimates. Previous studies ignored the unreliability of using predicted EQ-5D scores and the errors of mortality estimates in small cells [8, 25]. This study provides a method to include this extra variability for the standard error estimation. Such corrections allow the use of model-based estimates of death rates and EQ-5D scores for areas with few or no deaths or BRFSS respondents and are particularly important for estimating QALE in small states or in counties [20].

Although QALE among U.S. adults have increased progressively from 1993 to 2008, mainly due to the consistent decline in mortality rates in major population subgroups [18], such improvements of QALE differed across different demographic subgroups and did not occur in all U.S. States. Observed differences among the States in QALE imply differences in state-specific life expectancies, HRQOL scores, or both. Because states with high mortality rates are more likely to have worse HRQOL scores, we would expect the state QALE differences to be even bigger than observed differences in life expectancy and HRQOL alone. Interventions to increase life expectancy, to improve HRQOL, or both may help reduce differences among the States in their progress toward achieving goal 1 of Healthy People 2020, to increase quality and years of healthy life [3].

Besides some inherent limitations of BRFSS data (such as the use of self-reported data, and the omission of persons who use only cell phones or who are in institutions) [9, 11, 12], this study has some other limitations in estimating QALE. First, the QALE estimation uses an estimated preference-based HRQOL score instead of actual observed scores because the BRFSS does not include the EQ-5D questions. The estimated EQ-5D scores may be biased for some demographic subgroups, which in turn can bias the calculated QALE when based on race [13–15, 26]. However, the bias of the mapping algorithm between the BRFSS HRQOL questions and the EQ-5D scores was relatively small for the estimation of mean utility values for the total population and some major demographic subgroups (<0.5%) [15]. Also, the sensitivity analysis demonstrated that the bias associated with using this mapping algorithm had little impact on estimated QALEs (see table 4).

Secondly, the number of BRFSS respondents and the number of deaths might be too small in some states when calculating life expectancy and QALE by race. Estimates in smaller population subgroups may require the construction of abridged life tables for the calculation of life expectancy and QALE [5, 6]. Third, in 2002, 28 states and the District of Columbia did not ask the Healthy Days questions in the BRFSS. The estimated values for these states and District of Columbia were based on 3-year moving averages.

In summary, this paper provided a new method for measuring QALE and tracking changes in the US States. Such a measure is particularly useful because it captures the population overall health associated with both mortality and morbidity using a single value. This study will enable the CDC and the State Health Departments to assess progress in the States toward the first goal of the Healthy People 2020 process, to increase both the quality and the years of healthy life [3].

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