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Summary Measures of Population Health: Methods for Calculating Healthy Life Expectancy

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Abstract

This report is one of several appearing as *Healthy People Statistical Notes* that evaluate methodological issues pertaining to summary measures. Summary measures of population health are statistics that combine mortality and morbidity to represent overall population health in a single number—in this report, health expectancy measures. This report presents a comprehensive discussion of the methods for calculation and methodologic issues related to the interpretation of healthy life expectancy. These measures combine both mortality and morbidity using an abridged life-table procedure. Data from the National Center for Health Statistics and other sources will be used to illustrate the calculation of the statistics and the associated statistical tests.

Key words: summary measures • compression of morbidity • life table • life expectancy • healthy life expectancy • healthy years.

Introduction

For the populations of the industrialized nations of the world, the 20th century has been a period of both demographic and epidemiologic transitions. In addition to the substantial decrease in fertility during this period, all industrialized countries experienced huge declines in crude death rates and infant mortality rates. This resulted in an impressive rise in the average life expectancy. For example, in the United States during the first half of the century, the average expectation of life at birth for the total population increased by nearly 45 percent—from 47.3 years in 1900 to 68.2 years by 1950 (1), a gain of nearly 21 years. In the second half of the century, mortality in the United States continued to decline, though at a much slower rate compared with the first half of the century. For example, from 1950–98 the average expectation of life at birth increased from 68.2 to 76.7 years, a gain of only 8.5 years.

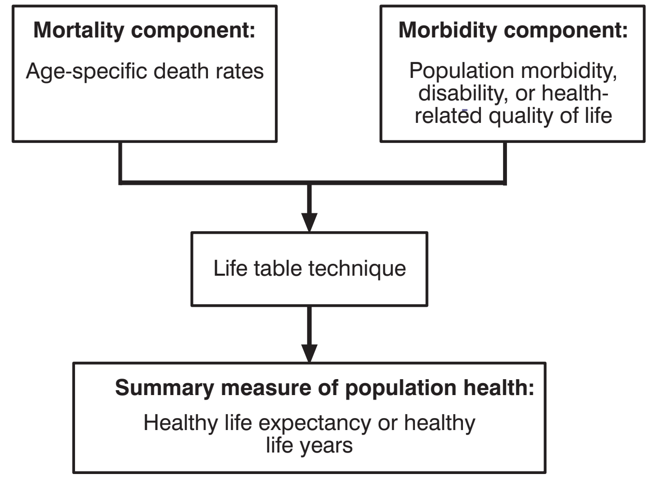
The substantial gain in life expectancy during the first half of the century caused a dramatic change in the age structures of the populations of these industrialized countries in the second half of the century. The longer average life span meant a sharp rise in the percent of the elderly population. There was also a sharp rise in noncommunicable chronic and degenerative diseases primarily affecting the older population. In the United States, the combined effect of these changes has encouraged a shift in focus from longevity to preventing disability, improving functioning, and relieving physical pain and emotional distress (2). This also meant that population health measures were needed to account for morbidity as well as longevity (3). One group of measures that included both of these components are health measures broadly known as ''healthy life expectancy'' (HLE).

Healthy Life Expectancy

The development of health measures that include both mortality and morbidity conditions of the population has been a focus of study since the 1960's. After Sanders published the results of his research on measuring community health levels (4), HLE estimates were published by the U.S. Department Health, Education, and Welfare for the first time in 1969 (5). Sullivan (6) later published the methods for calculating these estimates. At that time, the World Health Organization (WHO) noted that the fundamental objective of human activity should include both long life as well as good health. They expanded the definition of health as ''a state of complete physical, mental and social well-being.'' Both WHO and the Organization for Economic Cooperation and Development reported on healthy life (7). In 1974, WHO recommended that ''person-years of life in health'' be calculated and be compared with the total person-years of life (8).

In the 1980's, two new concerns became important, the relationship between changes in mortality and morbidity and the relatively greater burden of morbidity in the older ages. Debate centered on whether the factors responsible for the reductions in mortality would have a similar effect on morbidity. Some argued that most of the years of life that the elderly gained due to the decline of mortality were ''healthy years'' because morbidity was being pushed to the last few years of life, the compression of morbidity (9, 10). Others argued that the mortality decline observed over the past several decades was more likely to be the result of improvements in health care that saved more lives rather than either disease prevention that maintains healthy states or medical care that delays functional consequences of disease (11).

At the same time, Manton (12) introduced the concept of dynamic equilibrium. The theory of dynamic equilibrium is that chronic diseases have become less of a problem because deterioration in health due to disease has slowed down. The argument further suggested that while the decrease in mortality might have contributed to an increase in the prevalence of chronic diseases, these diseases would be of milder character leading to an overall better quality of life. Clearly, the issues related to the compression of morbidity further made clear that health status was a consequence of an interaction between mortality and morbidity, both at the micro and macro levels.



SOURCE: Adapted from a model by the Institute of Medicine, National Academy of Sciences (2).

Figure 1. A schematic presentation of the model

Encouraged by the basic idea of developing health measures that incorporate mortality and morbidity and motivated by the concept of compressing morbidity, health researchers continued to study empirical and methodologic issues throughout the 1990's (see appendix). Empirical studies estimated healthy life expectancy indexes based on a variety of health attributes. The name given the various HLE indexes depends on methods by which different health states are measured (13). When health states are measured based on broadly defined chronic or acute morbid conditions, the more general name ''healthy years'' or ''healthy life expectancy'' is used . However, when health states are defined based on social or functional limitation, the estimated index is called ''disability-free life expectancy.'' When health states are measured by activity limitation, the index is often called ''active life expectancy.''

Components of Healthy Life Years

The estimation of healthy life expectancy is based on the concept of a closed population within a given period of time, that is, a population with no immigration or emigration. The period of time may be of any length, but the most commonly used period is one year. At the end of the year, the population can be partitioned into those who died within the period and those who are still alive. Of those still alive, the majority are expected to be healthy, and some are expected to be unhealthy. Hence, a model can be built that measures the health status of persons who are alive at the same time it accounts for those who die in the period of time. Such a model is schematically presented in figure 1.

According to this model, healthy life expectancy is a summary measure of a population composed of two sets of partial measures. The first set of measures, the age-specific death rates, accounts for the mortality component. The second set of measures, the age-specific rates of population

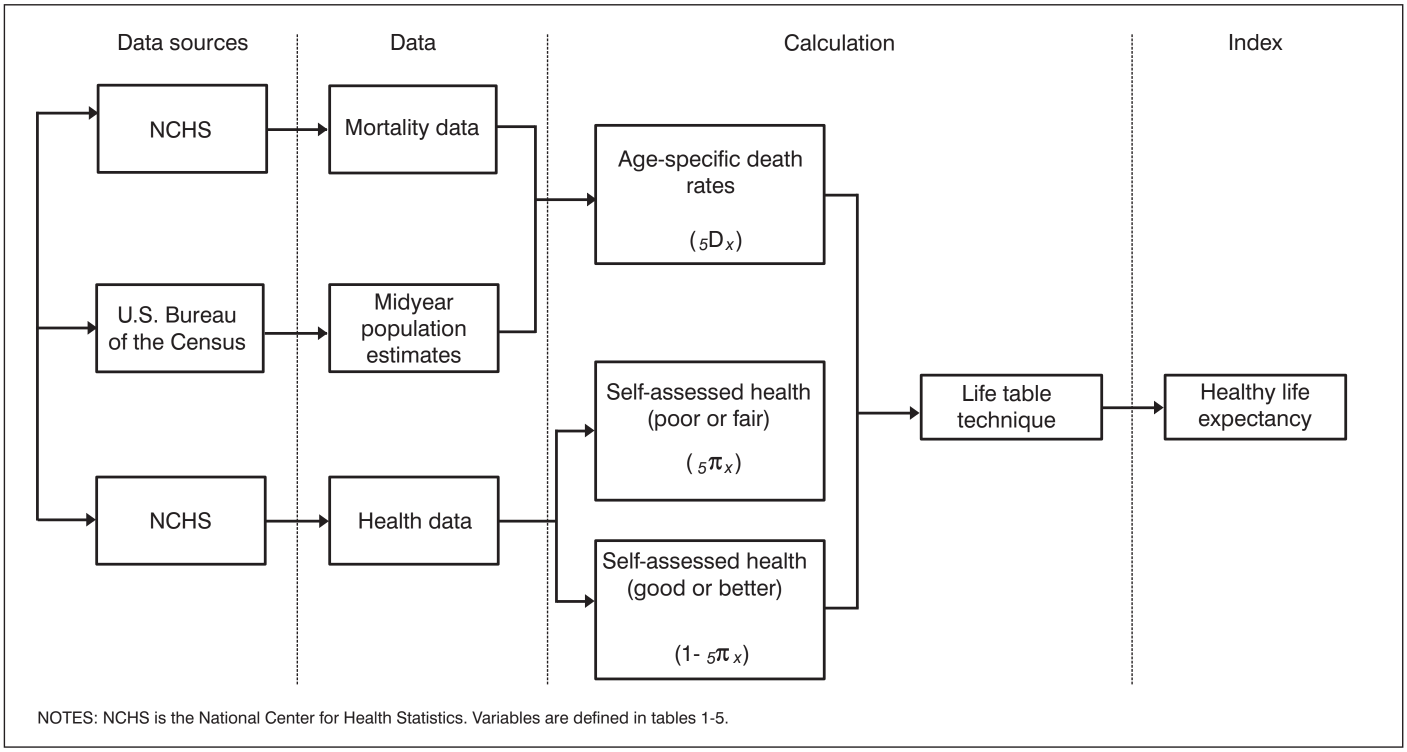


Figure 2. A schematic framework for estimating healthy life expectancy at the national level using respondent-assessed health status as an example

morbidity, disability, or health-related quality of life,[1] accounts for the morbidity component. These two components are combined using a mathematical function that transforms the two sets of partial measures into a single composite measure using a life table methodology. Figure 2 displays the framework of this calculation, including the type of data needed and the techniques used to estimate the two components of the measure at the national level.

At the national level, the mortality data are obtained from the National Vital Statistics System of the National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention. Mortality data are collected by each state and the District of Columbia and compiled at the national level by NCHS. Midyear population estimates are from the U.S. Bureau of the Census.

Health data can come from a number of different sources depending on the type of health measure and the population being considered. Boyle and Torrance (14) developed a "health state classification system" (displayed in part in figure 3). Only some health attributes are interrelated. Hence, attributes can be classified to show similarities and differences. The classification system of Boyle and Torrance conceptualizes the interrelationship of health attributes as hierarchal, based on breadth and on coverage of different aspects of health. For example, physical function, which is one of the primary-level health attributes, has four secondary-level attributes, one of which is self-care. Self-care may, in turn, be disaggregated into more specific health attributes, shown as the third level of classification in figure 3. The interpretation of the HLE depends on the health data used to estimate the statistic.

Because national data for respondent-assessed health are evaluated in the example presented here, the National Health Interview Survey (NHIS) conducted by NCHS is used. To calculate the age-specific prevalence rates of being healthy,

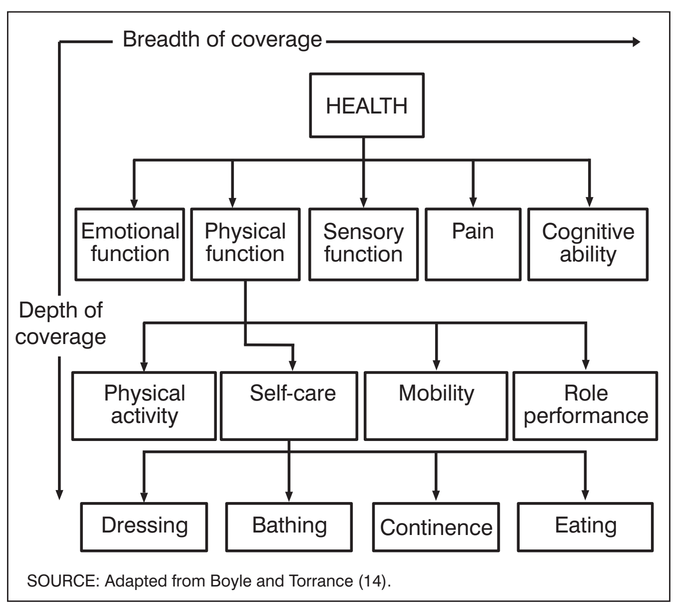


Figure 3. An example of a classification system for health attributes

[1]Health related quality of life (HRQOL) refers to the effect of health conditions on function. It focuses on the qualitative dimension of functioning and incorporates duration of stay in various health states (Kaplan and Anderson (15)).

first calculate the rates of reporting ‘‘fair or poor’’ health ($_n\pi_x$). The rates of being healthy, that is, reporting ‘‘good or better’’ health is then $(1-{}_n\pi_x)$. Then for each age interval $(x, x+n)$, the rates of being healthy $(1-{}_n\pi_x)$ are multiplied with the total number of years lived within the same age interval ($_nL_x$) to estimate the total number of years a group of persons is expected to live in a healthy state during the interval. The age interval $(x, x+n)$ is equal to 1 if data used are in single-year age groups, or 5 or 10 if data used are in 5- or 10-year age groups.

The model used to estimate healthy life expectancy (i.e., the expected number of years in good or better health) is:

$$e'_x = \frac{1}{l_x} \sum_{i=x}^{w} (1-{}_n\pi_x)\, {}_nL_i \tag{1}$$

where

e'_x is healthy life expectancy at age x, or the number of remaining years of healthy life for persons who have reached age x

l_x is the number of survivors at age x

$(1-{}_n\pi_x)$ represents the age-specific rate of being healthy

$_nL_x$ is the total number of years lived by a cohort in the age interval $(x, x+n)$

w is the oldest age category

HLE could be estimated using a variety of health attributes. For example, the model may be used to estimate disability-free life expectancy or life without activity limitation, also referred to as expected years of active life. Regardless of the health attribute chosen, however, the model uses two separate and independent partial health measures: $(1-{}_n\pi_x)$ for the morbidity component and l_x and $_nL_x$ for the mortality component.

Life Table Technique

The life table, also known as the mortality table, is used to present the most complete statistical description of mortality (16). The life table has also been an important tool of demographers who are interested in estimating the probability of marriage and remarriage, widowhood, becoming an orphan, and migration and population projections (17). In addition to the analyses of mortality and other demographic characteristics of human populations, the life table technique has been used to measure decrements in nonhuman groups or aggregates, including animals, insects, cases of illness, or even items of industrial equipment (18). The technique has been used to estimate risks and insurance benefits and school life (19), and even used to analyze prime time programs on a television network (20).

The method of calculating HLE is presented in this report in four parts. Healthy life expectancy is a modified life expectancy calculation. Therefore, the method is best presented by showing the calculations of life expectancy and discussing the modifications. Part I addresses the estimation of life table values. Part II presents the estimation of age-specific prevalence rates of health states and how the two partial measures of the mortality and morbidity components are combined to estimate the final age-specific composite health measure. Part III covers the estimation of the standard errors of healthy life expectancy. Part IV explains the application of the estimated healthy life expectancy and the associated standard errors in the statistical testing of health disparity between population subgroups.

Estimating Average Life Expectancy

The objective of the life table is to calculate the expected life expectancy of groups of people currently at specified ages if they lived the rest of their lives experiencing the age-specific mortality rates observed for the population at a specific time. The technique, therefore, uses the age-specific mortality to calculate the proportion of people alive at the beginning of an age interval who die before reaching the next age group. The average number of person-years lost because of those deaths is then subtracted from the total possible person-years for the age group of the cohort. These person-years are then added for all the age groups being considered to yield the expected number of years remaining. The method for constructing a complete annual life table is discussed in another NCHS publication (21).

The estimation of life table values, such as the expectation of life, begins with the computation of age-specific death rates. An illustrative example is presented in table 1 using 1995 data for white females in the United States. The two sets of data required to construct a life table are the midyear population and the number of deaths in that year. These data could be analyzed in single years of age or 5- or 10-year age groups. The process could be applied to the construction of a life table for national, state, or local populations.

In the first column, the age groups are listed. In the example shown in table 1, the initial 5-year age group is 0–4 years[2] and the final age groups is 85 years and over. The determining factor for the age grouping is the availability and quality of data. It should be noted that the age that begins the final age group (also known as the open age interval) does not have any effect on the life table being constructed.

The next two columns of the table give counts for the population $_nP_x$ and deaths $_nD_x$ for each age group. The population counts are based on midyear estimates. The deaths are for the entire year. These are used to compute the average death rate of each age-group for the year ($_nM_x$, where n, the number of years in the age groups is 5 in table 1), as

$${}_nM_x = {}_nD_x \,/\, {}_nP_x \tag{2}$$

[2]Mortality rates for age 0 and age group 1–4 are calculated separately when knowing ‘‘their pattern in more detail’’ is preferred (22).

Table 1. Life table for white females: United States, 1995

Age interval[1]	Mid-year population	Number of deaths	Age-specific deaths per 1,000	Proportion of years lived by those who die in age interval[2]	Probability of dying during age interval	Number alive at the beginning of age interval	Total number of years lived in age interval	Number of years lived in this and subsequent age intervals	Life expectancy at beginning of age interval
x to x+5	$_5P_x$	$_5D_x$	$_5M_x$	a_x	$_5q_x$	l_x	$_5L_x$	T_x	e_x
0–4 years	7,530,865	10,277	1.3647	0.178	0.0068	100,000	497,211	7,945,930	79.5
5–9 years	7,375,960	1,112	0.1508	0.477	0.0008	99,321	496,412	7,448,720	75.0
10–14 years	7,294,788	1,335	0.1830	0.530	0.0009	99,247	496,020	6,952,308	70.1
15–19 years	7,010,351	3,084	0.4400	0.555	0.0022	99,156	495,294	6,456,288	65.1
20–24 years	7,020,389	3,102	0.4419	0.517	0.0022	98,938	494,163	5,960,994	60.3
25–29 years	7,583,792	4,067	0.5363	0.519	0.0027	98,720	492,962	5,466,831	55.4
30–34 years	8,918,195	6,554	0.7349	0.538	0.0037	98,455	491,441	4,973,870	50.5
35–39 years	9,190,371	9,651	1.0501	0.524	0.0052	98,094	489,247	4,482,429	45.7
40–44 years	8,478,260	12,541	1.4792	0.524	0.0074	97,580	486,191	3,993,182	40.9
45–49 years	7,485,773	17,056	2.2784	0.528	0.0113	96,861	481,715	3,506,991	36.2
50–54 years	5,969,413	22,572	3.7813	0.531	0.0187	95,764	474,612	3,025,276	31.6
55–59 years	4,913,335	29,877	6.0808	0.534	0.0300	93,969	463,278	2,550,664	27.1
60–64 years	4,570,327	44,926	9.8300	0.534	0.0480	91,152	445,546	2,087,386	22.9
65–69 years	4,728,330	71,430	15.1068	0.534	0.0730	86,772	419,113	1,641,841	18.9
70–74 years	4,451,633	105,434	23.6844	0.539	0.1123	80,441	381,366	1,222,727	15.2
75–79 years	3,573,206	134,299	37.5850	0.543	0.1730	71,408	328,775	841,361	11.8
80–84 years	2,603,800	163,724	62.8788	0.529	0.2739	59,051	257,187	512,586	8.7
85 years and over	2,405,023	349,118	145.1620	0.596	1.0000	42,880	255,399	255,399	6.0

[1]Mortality rates for those less than 1 year and age group 1–4 years are calculated separately when knowing “their pattern in more detail” is preferred (22).
[2]For a more detailed discussion of a_x, see DHEW (24) and Keyfitz (27).

The computed age-specific death rates need to be checked for stability. Age-specific death rates are considered to be stable if they are based on 20 or more deaths. Rates based on fewer than 20 deaths have a relative standard error of 23 percent or more and therefore are considered highly variable (23).

The conditional probability of dying within a given age group $_nq_x$ is given in column 6. This is the proportion of people in the age group alive at the beginning of the age interval who die before reaching the next age group. Whereas $_nM_x$ is an annual death rate, $_nq_x$ is a conditional probability of dying. This probability is estimated as:

$$_nq_x = [n \bullet {_nM_x}] / [1+n(1-a_x)\, {_nM_x}] \tag{3}$$

where a_x is average proportion of years lived by those who died in this age interval (given in column 5). The conditional probability of dying is assumed to be 1.0 for the open, oldest age interval. In the example presented here, n is 5 years, so the probability becomes:

$$_5q_x = [5 \bullet {_5M_x}] / [1+5(1-a_x)\, {_5M_x}]$$

The values for a_x are constants derived from the complete U.S. life tables of 1949–51 (24). For single-year life table value calculations, a_x may be assumed to be ½.

Having calculated the conditional probability of dying, one can now calculate the probability of surviving to an exact age marking the beginning of an interval. In the life table, this is expressed as the number of persons surviving to an exact age (or the exact age at the beginning of an age interval when group data are used), starting with an assumed cohort population (l_0) frequently expressed as 100,000 at birth (column 7). For any other specific age, the number of survivors at that age, (l_x) can be calculated. Hence, the number alive at exact age $x+n$ (l_{x+n}) is calculated by multiplying the number of survivors at exact age x (l_x) by the probability of surviving from age x to age $x+n$ ($1-{_nq_x}$) or:

$$l_{x+n} = l_x\,(1-{_nq_x}) \tag{4}$$

The total number of person-years lived for those people who began the age interval x to $x+n$ (column 8) is then the sum of the total number of years lived by individuals surviving to the end of the age interval plus the total number of years lived by those who die in the age interval. This becomes:

$$_nL_x = n\,[l_{x+n} + a_x\,(l_x - l_{x+n})] \tag{5}$$

In the example presented here, n = 5 so,

$$_5L_x = 5\,[l_{x+5} + a_x\,(l_x - l_{x+5})]$$

Column 9, the person-years remaining for the population, that is, T_x, is the total of all the person-years for age x and all subsequent age groups, or:

$$T_x = \sum_{i=x} L_i$$

$$\text{for } i = x, x+n, \ldots, \text{ oldest age group} \tag{6}$$

The average per person expected years (column 10) is the total person-years divided by the number of persons surviving to the beginning of the age interval x, or:

$$e_x = T_x / l_x \tag{7}$$

Table 2. Calculation of healthy life expectancy for white females by Sullivan's method using abridged life table: United States, 1995

Age interval	Number alive at the beginning of each interval	Number of years lived in age interval	Proportion of persons in age interval in state considered unhealthy	Proportion of persons in age interval in healthy state	Number of healthy years lived in age intervals	Number of years lived in healthy state in this and all subsequent age intervals	Average number of years in healthy state remaining at beginning of age interval
x to $x+5$	l_x	${}_5L_x$	${}_5\pi_x$	$(1-{}_5\pi_x)$	${}_5L'_x$	T'_x	e'_x
0–4 years	100,000	497,211	0.0185	0.9815	488,012	6,981,686	69.8
5–9 years	99,321	496,412	0.0196	0.9804	486,682	6,493,674	65.4
10–14 years	99,247	496,020	0.0189	0.9811	486,645	6,006,992	60.5
15–19 years	99,156	495,294	0.0435	0.9565	473,749	5,520,347	55.7
20–24 years	98,938	494,163	0.0490	0.9510	469,949	5,046,598	51.0
25–29 years	98,720	492,962	0.0617	0.9383	462,546	4,576,649	46.4
30–34 years	98,455	491,441	0.0614	0.9386	461,266	4,114,103	41.8
35 –39 years	98,094	489,247	0.0773	0.9227	451,428	3,652,837	37.2
40–44 years	97,580	486,191	0.0890	0.9110	442,920	3,201,409	32.8
45–49 years	96,861	481,715	0.1094	0.8906	429,015	2,758,489	28.5
50–54 years	95,764	474,612	0.1506	0.8494	403,136	2,329,473	24.3
55–59 years	93,969	463,278	0.1919	0.8081	374,375	1,926,338	20.5
60–64 years	91,152	445,546	0.2031	0.7969	355,055	1,551,963	17.0
65–69 years	86,772	419,113	0.2257	0.7743	324,520	1,196,908	13.8
70–74 years	80,441	381,366	0.2364	0.7636	291,211	872,388	10.8
75–79 years	71,408	328,775	0.2782	0.7218	237,310	581,177	8.1
80–84 years	59,051	257,187	0.3298	0.6702	172,367	343,867	5.8
85 years and over	42,880	255,399	0.3285	0.6715	171,501	171,501	4.0

Therefore, in the example presented in table 1, the expected number of years of life at birth (e_0) is 79.5 years, the expected number of years of life at age 20 years (e_{20}) is 60.3 years, and the expected number of years of life at age 65 years (e_{65}) is 18.9 years.

Estimating Average Years of Healthy Life

The life table technique is a powerful tool for estimating the remaining years of life that a group of persons can expect to live once they had reached a certain age. Regardless of their age, the remaining years of life might be lived in good health, in less optimal health status, or some combination of both. The traditional life table technique does not distinguish between remaining healthy years and unhealthy years. Additional data are needed to disaggregate the total number of years into expected years of healthy and of unhealthy life.

Using health data, the total number of expected years of life are separated into healthy and unhealthy years (see figure 2). In general, health data, collected through health surveys or from clinical observations, are used to estimate the prevalence of different levels of health status. The population is then partitioned into proportions that are experiencing varying levels of health status. The separation may be as simple as dividing the population into those who are healthy or unhealthy. Or the population may be separated into more than two population subgroups according to varying levels of health status using multidimensional scaling to describe health status.

To calculate the HLE, the population of each age interval in the life table is separated into the proportion experiencing an unhealthy condition (${}_n\pi_x$) and those considered as healthy ($1-{}_n\pi_x$). An example is shown in columns 4 and 5 of table 2. Because ${}_nL_x$ is the total number of person-years lived for the population in age interval x to $x+n$ (equation 5), the proportion of these years lived in a healthy state (${}_nL'_x$) is then:

$$ {}_nL'_x = (1-{}_n\pi_x)\ {}_nL_x \tag{8} $$

This is shown in column 6 of table 2. Equations (6) and (7) can then be used to obtain the healthy life expectancy (see column 8 of table 2) from the number of healthy person-years determined in (8) or

$$ e'_x = \frac{1}{l_x} \sum_{i=x}^{w} {}_nL'_i \tag{9} $$

The expected years of unhealthy life are $e_x - e'_x$. However, if multiple states of health status are described, the prevalence for each of those states for each age interval must be calculated and equations similar to (8) and (9) are used to estimate separately the expected years of life in those health states.

In table 2, the health states have been defined using respondent-assessed health, which is obtained from health interview surveys using the question, ''Would you say your health in general is excellent, very good, good, fair or poor'' with five response categories: excellent, very good, good, fair, and poor. Health states are then defined as two mutually exclusive states: self-assessed health as poor or fair (column 4) and self-assessed health as good or better (column 5). The number of survivors at exact age x (l_x) and number of

Table 3. The variance and standard error of healthy life expectancy for white females assuming simple random sampling: United States, 1995

Age interval	Number of years lived in age interval	Average number of years of healthy life remaining at beginning of age interval	Number of persons in survey in age interval	Proportion of persons in age interval in healthy state	Variance of the prevalence rates in age interval	Variance of healthy life expectancy in age interval	Standard error of healthy life expectancy in age interval
x to $x+5$	${}_5L_x$	e'_x	${}_5N_x$	$(1-{}_5\pi_x)$	$S^2({}_5\pi_x)$	$\mathrm{VAR}(e'_x)$	$s(e'_x)$
0–4 years	497,211	69.8	3,170	0.9815	0.000006	0.01812	0.135
5–9 years	496,412	65.4	3,282	0.9804	0.000006	0.01823	0.135
10–14 years	496,020	60.5	3,221	0.9811	0.000006	0.01811	0.135
15–19 years	495,294	55.7	2,840	0.9565	0.000015	0.01800	0.134
20–24 years	494,163	51.0	2,685	0.9510	0.000017	0.01771	0.133
25–29 years	492,962	46.4	3,033	0.9383	0.000019	0.01735	0.132
30–34 years	491,441	41.8	3,411	0.9386	0.000017	0.01697	0.130
35–39 years	489,247	37.2	3,648	0.9227	0.000020	0.01667	0.129
40–44 years	486,191	32.8	3,365	0.9110	0.000024	0.01635	0.128
45–49 years	481,715	28.5	2,848	0.8906	0.000034	0.01599	0.126
50–54 years	474,612	24.3	2,246	0.8494	0.000057	0.01549	0.124
55–59 years	463,278	20.5	1,828	0.8081	0.000085	0.01464	0.121
60–64 years	445,546	17.0	1,730	0.7969	0.000094	0.01336	0.116
65–69 years	419,113	13.8	1,764	0.7743	0.000099	0.01228	0.111
70–74 years	381,366	10.8	1,634	0.7636	0.000110	0.01160	0.108
75–79 years	328,775	8.1	1,207	0.7218	0.000166	0.01157	0.108
80–84 years	257,187	5.8	813	0.6702	0.000272	0.01176	0.108
85 years and over	255,399	4.0	625	0.6715	0.000353	0.01252	0.112

person-years (${}_nL_x$) have been copied from table 1 into the second and third columns of table 2. The healthy person-years for each age group (column 6) is the multiple of columns 5 and 3. Using the equations above, the expected years of healthy life at age x (e'_x) can be calculated (column 8). Therefore, whereas the total expected life at birth (e_0) from table 1 is 79.5 years, the expected life lived in good or better health (e'_0) from table 2 is 69.8 years. The e'_0 may be interpreted as the number of years a newborn white female is expected to live in a healthy state provided that she experiences the 1995 age-sex-specific mortality and survey-measured age-sex-specific prevalence rates of good or better health that are given in table 2. Similarly, at age 65, the total expected life (e_{65}) is 18.9 years (table 1) and expected healthy life (e'_{65}) is 13.8 years (table 2), that is, whereas a female age 65 years is expected to live about 19 more years, only 14 of those years are expected to be in good or better health.

Statistical Test for HLE

The estimates for age-specific prevalence of healthy and unhealthy states are derived from surveys or samples. Consequently, these estimates have associated sampling error. Calculating the standard error of the resulting estimated HLE is especially important when comparing population subgroups. This section discusses the method of estimating the standard errors of HLE with and without information on the survey sample design. Standard errors of each of the other life table values can be calculated separately when needed. See Chiang (25) and Keyfitz (26) for details.

The variance estimation method will be illustrated with and without taking into account the sample survey design. The method that takes the sample survey design into account will be illustrated using the 1995 NHIS data in conjunction with the SUDAAN statistical software. The alternative method that assumes a simple nonstratified sample survey is presented to illustrate the application of the method when complete information on sample survey design is not available.

Standard Errors of HLE

Each age-specific value of the prevalence of the population experiencing healthy life ($1-{}_n\pi_x$) is an estimated proportion with an associated variance and standard error. Because the distribution of these proportions is binomial, the variance (S^2) is given by:

$$S^2({}_n\pi_x) = [{}_n\pi_x \bullet (1-{}_n\pi_x)] \,/\, {}_nN_x \tag{10}$$

where ${}_nN_x$ is the number of persons in the age interval (x, $x+n$) of the sample from which the prevalence rates were computed.

The variances of the prevalence rates from equation (10) can be used to estimate the overall variance of e'_x by:

$$\mathrm{VAR}(e'_x) = \frac{1}{l_x^2}\sum_{i=x}^{w}[{}_xL_i^2 \bullet S^2(1-{}_n\pi_x)] \tag{11}$$

Table 4. Estimated variance and standard error of healthy life expectancy for white females taking the sample design of the health survey into account: United States, 1995

Age interval	Average number of years of life remaining at beginning of age interval	Average number of years of healthy life remaining at the beginning of age interval	Proportion of persons in age interval in healthy state	Variance of the prevalence rates in age interval estimated without SUDAAN	Variance of the prevalence rates in age interval estimated using SUDAAN	Variance of healthy life expectancy in age interval estimated using SUDAAN	Standard error of healthy life expectancy in age interval estimated using SUDAAN
x to x+5	e_x	e'_x	$(1-{}_5\pi_x)$	$s^2(1-{}_5\pi_x)$	$s^2(1-{}_5\pi_x)$	$VAR(e'_x)$	$s(e'_x)$
0–4 years	79.5	69.8	0.9815	0.000006	0.000007	0.02050	0.143
5–9 years	75.0	65.4	0.9804	0.000006	0.000006	0.02061	0.144
10–14 years	70.1	60.5	0.9811	0.000006	0.000006	0.02048	0.143
15–19 years	65.1	55.7	0.9565	0.000015	0.000019	0.02036	0.143
20–24 years	60.3	51.0	0.9510	0.000017	0.000020	0.01997	0.141
25–29 years	55.4	46.4	0.9383	0.000019	0.000022	0.01955	0.140
30–34 years	50.5	41.8	0.9386	0.000017	0.000018	0.01910	0.138
35–39 years	45.7	37.2	0.9227	0.000020	0.000019	0.01878	0.137
40–44 years	40.9	32.8	0.9110	0.000024	0.000026	0.01849	0.136
45–49 years	36.2	28.5	0.8906	0.000034	0.000037	0.01811	0.135
50–54 years	31.6	24.3	0.8494	0.000057	0.000064	0.01759	0.133
55–59 years	27.1	20.5	0.8081	0.000085	0.000104	0.01663	0.129
60–64 years	22.9	17.0	0.7969	0.000094	0.000119	0.01499	0.122
65–69 years	18.9	13.8	0.7743	0.000099	0.000104	0.01341	0.116
70–74 years	15.2	10.8	0.7636	0.000110	0.000125	0.01278	0.113
75–79 years	11.8	8.1	0.7218	0.000166	0.000182	0.01263	0.112
80–84 years	8.7	5.8	0.6702	0.000272	0.000266	0.01282	0.113
85 years and over	6.0	4.0	0.6715	0.000353	0.000416	0.01476	0.122

This variance estimation method assumes that the health data were collected through a simple, nonstratified sample survey, also referred to as simple random sample survey (27). Table 3 displays the results from table 2. The prevalence data in table 2 were derived from a survey of 43,350 white females who participated in the 1995 National Health Interview Survey (28). In table 3, the variance of these data are assumed to be the result of simple random sampling.

Column 4 of table 3 gives the number of persons in the survey who were in the specific age intervals (${}_nN_x$). The proportion of each age-specific population reporting good or better health ($1-{}_n\pi_x$) (column 5) are the same values shown in table 2. Equation 10 can be used to calculate the age-specific variances shown in column 6. The total variance of e'_x using equation 11 is shown in column 7. The standard error ($s(e'_x)$) of e'_x is given in column 8.

Many surveys, including NHIS, do not use simple random sampling to identify respondents. For surveys that use a complex multistage sample design, the sample design must be taken into account in the estimation of the variance and standard error (29). Computer programs exist that can compute the variance and standard errors using sample design variables to approximate the true variance and standard errors. One such program is SUDAAN (30). In table 4, the data presented previously have been reanalyzed using SUDAAN to develop estimates of the variance for age-specific prevalence (column 6). The binomial variance estimate of table 3 is also shown for comparison in column 5. Using equation 11, the variance and standard errors of healthy life expectancy were calculated. Estimates that incorporate information from the complex sample design may differ from those calculated using the simple random sampling assumption. In this example, the standard errors of the prevalence rates estimated using the SUDAAN procedure were 5–10 percent larger than those estimated using the binomial estimation.

Test for Difference Between Two Populations

Health disparity between two population subgroups can be tested using statistical methods usually used for testing the difference between two means. The estimated HLE within each age group is a mean of random variables assumed to be independent of each other and with normal distribution (31). Hence, a z-score[3] test can be constructed using the estimated HLE and the corresponding variance to compare the HLE's ($e'_{x,1}$ and $e'_{x,2}$) of two population subgroups at a specified age. Note that the specified age is the same for each HLE. Assuming $e'_{x,1}$ stands for healthy life expectancy of white females at a specific age and $e'_{x,2}$ is healthy life expectancy at the same age for white males, a score for testing a hypothesis about the equality of healthy life at that specified age can be stated as

$$z = \frac{e'_{x,1} - e'_{x,2}}{\sqrt{S^2(e'_{x,1} - e'_{x,2})}} \qquad (12)$$

[3]The z-score is a standard normal variable estimated by transforming a nonstandard normal variable x based on the statistical formula $z = (x - \mu_x) / \sigma_x$, where μ_x is the mean of the x-values and σ_x is the standard error (32, 33).

Table 5. Statistical test for disparity in healthy life expectancies at specific ages for the white population: United States, 1995

Age interval	Female: Healthy life expectancy	Female: Standard error of healthy life expectancy	Male: Healthy life expectancy	Male: Standard error of healthy life expectancy	Difference in healthy life expectancy	Approximate standard error of difference in healthy life expectancy	*z*-statistic	*p*-value $Pr(Z>=z)$
x to $x+5$	$e'_{x,1}$	$s(e'_{x,1})$	$e'_{x,2}$	$s(e'_{x,2})$	(2) – (4)	(3) + (5)	z	p
0–4 years	69.8	0.143	65.7	0.130	4.078	0.273	14.93	<0.001
5–9 years	65.4	0.144	61.5	0.130	3.931	0.274	14.37	<0.001
10–14 years	60.5	0.143	56.6	0.129	3.907	0.273	14.34	<0.001
15–19 years	55.7	0.143	51.8	0.129	3.878	0.272	14.28	<0.001
20–24 years	51.0	0.141	47.2	0.129	3.822	0.270	14.16	<0.001
25–29 years	46.4	0.140	42.6	0.128	3.730	0.268	13.91	<0.001
30–34 years	41.8	0.138	38.1	0.128	3.655	0.266	13.72	<0.001
35–39 years	37.2	0.137	33.7	0.128	3.495	0.265	13.19	<0.001
40–44 years	32.8	0.136	29.4	0.128	3.366	0.264	12.77	<0.001
45–49 years	28.5	0.135	25.2	0.128	3.242	0.262	12.36	<0.001
50–54 years	24.3	0.133	21.2	0.127	3.098	0.260	11.92	<0.001
55–59 years	20.5	0.129	17.6	0.125	2.918	0.254	11.49	<0.001
60–64 years	17.0	0.122	14.3	0.121	2.746	0.243	11.28	<0.001
65–69 years	13.8	0.116	11.4	0.119	2.379	0.234	10.15	<0.001
70–74 years	10.8	0.113	9.0	0.118	1.895	0.231	8.19	<0.001
75–79 years	8.1	0.112	6.8	0.121	1.354	0.234	5.79	<0.001
80–84 years	5.8	0.113	5.0	0.133	0.796	0.246	3.23	<0.002
85 years and over	4.0	0.122	3.7	0.168	0.271	0.289	0.94	<0.200

Because $S^2[e'_{x,1} - e'_{x,2}] \leq [S(e'_{x,1}) + S(e'_{x,2})]^2$, the z-score value may be conservatively approximated (34) using:

$$z \approx \frac{e'_{x,1} - e'_{x,2}}{S(e'_{x,1}) + S(e'_{x,2})} \qquad (13)$$

Table 5 presents 1995 data comparing white males and white females. The health expectancies and corresponding standard errors are given in columns 2–5. (The SUDAAN estimates of the standard errors of the age-specific prevalence rates are used in this table.) The difference between health expectancies is given in column 6, and the approximate standard error is given in column 7. The z statistics, shown in column 8, range from 14.93 for age group 0–4 years to 0.94 for ages 85 years and over. The critical value of the z-score for a two-tailed test at the 95 percent level of significance is 1.96 (table 6). Because the computed z-statistics are larger than the observed z-score at all ages except at ages 85 years and over, the hypothesis that the HLE's of white males and white females are equal is not accepted for all age groups except at age 85 years and over. Thus, the test shows that a significant difference exists between healthy life expectancies of white males and white females at all ages except 85 years and over. The z-statistics were also calculated using the binomial estimate of the standard error (data not shown). In this example, the same conclusions resulted from the statistical tests using either method of estimating the standard error.

Table 6. Critical values of the standardized normal variable *z*

Level of significance for a two-tail test	Level of significance for a one-tail test	*z*-critical values
0.200	0.100	1.28
0.100	0.050	1.645
0.050	0.025	1.96
0.020	0.099	2.33
0.010	0.005	2.58
0.002	0.001	3.09
0.001	0.0005	3.29

SOURCE: Murdoch and Barnes (34).

Appendix

Selected publications related to healthy life expectancy:

I. Publications on methodology

A. Theoretical publications
1. Mathematical modeling (35)
2. Validity tests (36)
3. Choosing the appropriate measures (37)
4. Global disability indicators (38)
5. Mental health indicators (39)
6. New methods (40)

B. Theoretical background and policy implications
1. Quality of life (41, 42)
2. Life tables and Sullivan's method (43)

3. Population health leading indicators (44)
4. Issues related to health measures (45, 46)
5. Policy implications of measures (47)
6. Measures of health in the 1990s (48)

II. Empirical publications

A. Healthy life
1. Years of healthy life (49)
2. Healthy life expectancy (50)
3. Healthy aging (51)

B. Life without disability
1. Disability-free life expectancy (52)
2. DFLE among the elderly (53)
3. Disability-adjusted life expectancy (54)

C. Active life
1. Active life expectancy (55)
2. Educational status and active life expectancy (56)
3. Active life expectancy in older populations (57, 58)
4. Causes of death and active life expectancy (59)

D. Health status, morbidity, and life expectancy
1. Health status and life expectancy (60)
2. Longevity and expansion of morbidity (61).

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Selected published issues of Healthy People Statistical Notes

Number	Title	Date of Issue
Healthy People 2000		
2	Infant Mortality	Winter 1991
6	Direct Standardization (Age-Adjusted Death Rates)	March 1995
7	Years of Healthy Life	April 1995
19	Healthy People 2000: An Assessment Based on the Health Status Indicators for the United States and Each State	November 2000
Healthy People 2010		
20	Age Adjustment Using the 2000 Projected U.S. Population	January 2001

NOTE: These issues of Healthy People Statistical Notes deal with statistical issues affecting the tracking of Healthy People 2010.

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