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HINTS AND KINKS

Calculating disability-adjusted life years to quantify burden of disease

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Introduction

The disability-adjusted life year or DALY is a summary measure of public health widely used to quantify burden of disease. In the DALY philosophy, every person is born with a certain number of life years potentially lived in optimal health. People may lose these healthy life years through living with illness and/or through dying before a reference life expectancy. These losses in healthy life years are exactly what is measured by the DALY metric. Ten DALYs, for instance, correspond to ten lost years of healthy life, attributable to morbidity, mortality, or both. On a population level, diseases with a higher public health impact will thus account for more DALYs than those with a lesser impact.

DALYs have been the key measure in the four Global Burden of Disease (GBD) studies, each presenting a comprehensive assessment of the worldwide health impact of disease, injury and risk factors (Murray and Lopez 1996; Lopez et al. 2006; World Health Organization 2008; Murray et al. 2013a; Lopez 2013). Table 1 shows the most important diseases according to the different GBD studies. Furthermore, various national and regional DALY calculations have been performed to assess and monitor local health and to set priorities within the local health sector (e.g., Melse et al. 2000; Mathers et al. 2001; Devleesschauwer et al. 2013; Shield et al. 2013).

In this Hints and Kinks paper, we summarize the DALY's basic features and present a description of its calculation. An "Appendix" includes R code to calculate DALYs. The

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Table 1 Top three diseases according to the different Global Burden of Disease studies

	Murray and Lopez (1996)	Lopez et al. (2006)	World Health Organization (2008)	Murray et al. (2013a)
Reference year	1990	2001	2004	2010
Top three diseases	Lower respiratory infections	Perinatal conditions	Lower respiratory infections	Ischaemic heart disease
	Diarrhoeal diseases	Ischaemic heart disease	Diarrhoeal diseases	Lower respiratory infections
	Perinatal disorders	Lower respiratory infections	Unipolar depressive disorders	Stroke

companion paper (Devleesschauwer et al. 2014) presents a stepwise approach towards conducting a DALY assessment study. These papers may serve as a guide and reference for public health professionals interested in quantifying burden of disease (Bjegovic-Mikanovic et al. 2013).

Basic formulae

DALYs are composed of years lived with disability (YLDs) and years of life lost due to premature mortality (YLLs). YLDs, the morbidity component of the DALYs, are calculated as follows

$$\begin{aligned}\text{YLD} = {} & \text{Number of cases} \\ & \times \text{duration till remission or death} \\ & \times \text{disability weight}\end{aligned} \quad (1)$$

The disability weights (DWs) are a crucial component of the DALY calculation, as they translate morbidity into healthy life years lost, thus enabling comparison of morbidity and mortality. A DW, scaled from zero (perfect health) to one (worst possible health state), can be interpreted as the proportional reduction in good health due to an adverse health state. In the DALY mindset, this is set equivalent to losing the same proportion of healthy life years over the course of the disability. Living 10 years with a DW of 0.10, or 5 years with a DW of 0.20, thus both correspond to losing one full healthy life year. For example, a female patient develops severe alcohol use disorder at age 40 and consequently dies at age 60. This condition has a DW of 0.55 (Salomon et al. 2013), and is thus assumed to cause a 55 % reduction of good health, or, equivalently, a loss of 55 % of the potential healthy life years lived during the 20 years of suffering from this condition. The number of YLDs for this patient is therefore calculated as:

$$\text{YLD} = 1 \times (60 - 40) \times 0.55 = 11$$

YLLs, the mortality component of the DALYs, are calculated as follows:

$$\begin{aligned}\text{YLL} = {} & \text{Number of deaths} \\ & \times \text{life expectancy at the age of death}\end{aligned} \quad (2)$$

The first three GBD studies use the life expectancy at the age of death from the Coale–Demeny Model Life Table West. This table has a life expectancy at birth of 80 for males and 82.5 for females (Murray 1994). In the latest GBD study, a new model life table was developed, with a life expectancy at birth of 86 for both males and females (available as a supplement in Murray et al. 2013b). Alternatively, local life tables may be used instead of standard life tables.

Continuing the aforementioned example, the life expectancy of 60-year-old females are 25 years in the Coale–Demeny Model Life Table West. Dying at the age of 60 will thus cause a loss of 25 full life years potentially lived in optimal health:

$$\text{YLL} = 1 \times 25 = 25$$

DALYs are simply the sum of the YLDs and YLLs:

$$\text{DALY} = \text{YLD} + \text{YLL} \quad (3)$$

For our patient, this would mean 11 YLDs + 25 YLLs = 36 DALYs, which can be interpreted as a loss of 36 healthy life years. These 36 years (DALYs) are composed of the equivalent of 11 full healthy life years lost due to living in a less-than-optimal health state (YLDs), and the actual 25 healthy life years lost due to premature death (YLLs).

In population-based burden studies, average DALYs are calculated for specific age and sex strata, based on the total number of cases and deaths in each stratum, and the average duration, age at onset and age at death in each stratum. Population totals are then obtained by summing these stratum-specific DALYs.

Social weighting

The basic formulae for YLDs and YLLs may be extended by applying so-called social weighting functions. This implies that not all life years lost will be valued equally, and social weighting is therefore not universally accepted (Barendregt et al. 1996; Arnesen and Kapiriri 2004.

Age weighting, as used in the initial GBD study and many ensuing studies, implies that the value of life depends on age. A higher weight is given to the healthy life years lived in the (assumed) socially more important life span between 9 and 56 (Murray 1994).

The standard age weighting formula is:

$$Cxe^{-\beta x} \quad (4)$$

Table 2 Years lived with disability (YLDs), years of life lost (YLLs) and disability-adjusted life years (DALYs) for the alcohol use disorder example under different social value choices

Scenario [K; r]	Age weighting	Discount rate (%)	YLD	YLL	DALY
DALY [0; 0]	No	0	11.0	25.0	36.0
DALY [1; 0]	Yes	0	12.3	16.7	29.1
DALY [0; 0.03]	No	3	8.3	9.7	17.9
DALY [1; 0.03]	Yes	3	9.5	6.7	16.2

with x the concerned age, and C and β constants commonly set to 0.1658 and 0.04.

Time discounting discounts years of healthy life lived in the future at a rate of (usually) 3 %. This reflects similar practices in economic assessments, and would prevent policy makers from saving resources for a future eradication program, instead of investing in currently available, but less effective, intervention measures (Murray 1994).

The standard time discounting formula is as follows:

$$e^{-r(x-a)} \tag{5}$$

with r the discount rate, x the concerned age, and a the age to which the burden will be assigned.

Combining both social weighting functions gives the following extended YLD and YLL formulae:

$$\text{YLD} = N \times \text{DW} \times \int_{A}^{A+L} \left\{ KCxe^{-\beta x}e^{-r(x-a)} + (1-K)e^{-r(x-a)} \right\} \mathrm{d}x \tag{6}$$

$$\text{YLL} = M \times \int_{A}^{A+L} \left\{ KCxe^{-\beta x}e^{-r(x-a)} + (1-K)e^{-r(x-a)} \right\} \mathrm{d}x \tag{7}$$

where N equals the number of cases, M the number of deaths, and DW the disability weight. K is a modulating factor equalling one if age weighting is applied and zero otherwise; A and L represent, respectively, the age at onset and the duration (Eq. 6), or the age at death and the life expectancy at the age of death (Eq. 7).

The subjective choices of whether or not to apply age weighting and time discounting can have important effects on the DALY estimates. Only DALYs based on the same social value choices should therefore be compared. For illustration, we calculated DALYs for our example under different scenarios (Table 2; "Appendix"). Figure 1 visualizes these results (note that the integrals of Eqs. (6) and (7) translate to areas under the curve). Table 3 presents the social value choices applied by the four different GBD studies.

Given the lack of consensus on social weighting, we recommend to calculate DALYs under different scenarios. By calculating at least the DALY [0; 0], DALY [0; 0.03], and DALY [1; 0.03] scenario, comparability with most other studies is likely.

Presenting DALYs

DALYs can be expressed as an absolute number, thereby giving an idea of the total population burden. They can also be expressed relative to the population, e.g., as the number of DALYs per 1,000 population. This enables a direct

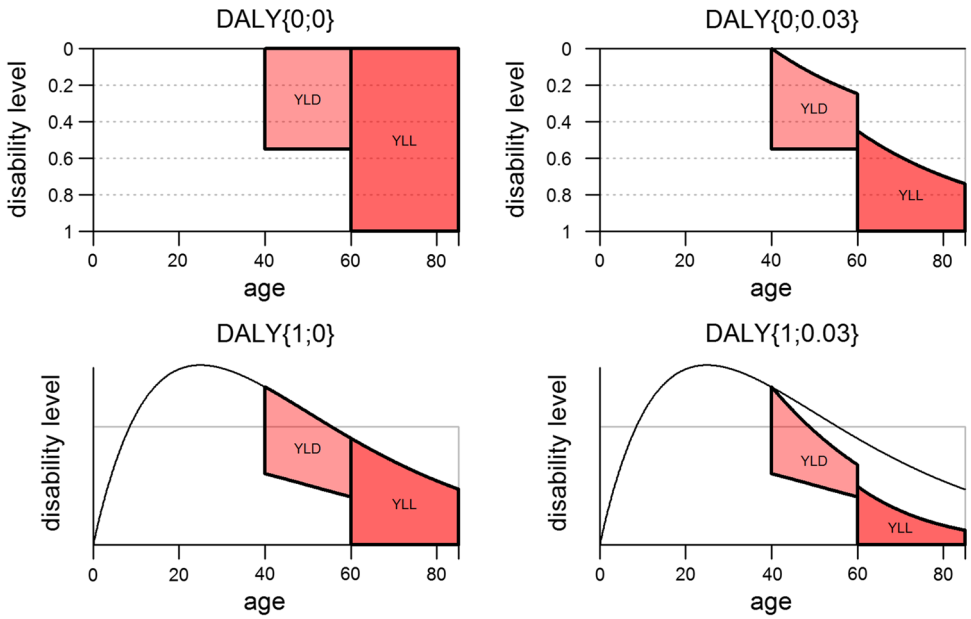

Fig. 1 Years lived with disability (YLDs) and years of life lost (YLLs) for the alcohol use disorder example under different social weighting scenarios. The *top left plot* is the basic disability-adjusted life year (DALY) calculation. The *bottom left plot* includes age weighting; the *curved black line* is the age-dependent zero disability level, while the *straight grey line* compares the situation without age weighting. The *top right plot* includes a 3 % time discount rate; the burden is assigned to the year of disease onset (i.e., the age of 40). The *bottom right plot*, finally, combines age weighting and a 3 % time discount rate

Table 3 Social value choices applied by the different Global Burden of Disease (GBD) studies

Study	Age weighting	Discount rate (%)	Scenario [K; r]
GBD 1990: Murray and Lopez (1996)	Yes	3	DALY [1; 0.03]
GBD 2001: Lopez et al. (2006)	No	3	DALY [0; 0.03]
GBD 2004: World Health Organization (2008)	Yes	3	DALY [1; 0.03]
GBD 2010: Murray et al. (2013a)	No	0	DALY [0; 0]

comparison of the burden suffered by different populations. Finally, DALYs may also be expressed relative to the number of cases. This allows comparisons of the impact of diseases at the patient-level, instead of at the population level.

All assumptions used in the DALY calculation should be explicitly mentioned, including DWs, life expectancy table and social weighting functions. This ensures correct interpretation of DALY estimates and reduces "error" variation between burden studies (Polinder et al. 2012).

Appendix: calculating DALYs in R

The following R code can be used to calculate DALYs:

```
## Helper function (calculates integral in Eq. (6) and (7))
f <-
function(x, K, C = .1658, beta = .04, r, a){
  K * C * x * exp(-beta * x) * exp(-r * (x - a)) +
  (1 - K) * exp(-r * (x - a))
}

## Burden calculation function (Eq. (6) and (7))
burden <-
function(N, DW, A, L, K, r, a){
  N * DW * integrate(f, lower = A, upper = A + L, K = K, r = r, a = a)$value
}

## The following code uses the alcohol use disorder example

## Select any of the following scenarios
K <- 0; r <- 0     # DALY[0;0]
K <- 1; r <- 0     # DALY[1;0]
K <- 0; r <- 0.03  # DALY[0;0.03]
K <- 1; r <- 0.03  # DALY[1;0.03]

## Calculate DALY = YLD + YLL
burden(N = 1, DW = 0.55, A = 40, L = 20, K = K, r = r, a = 40) +   # YLD
burden(N = 1, DW = 1.00, A = 60, L = 25, K = K, r = r, a = 40)     # YLL
```

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