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Original Research

The price of precision: trade-offs between usability and validity in the World Health Organization Health Economic Assessment Tool for walking and cycling

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ABSTRACT

Objectives: The widely used World Health Organization (WHO) Health Economic Assessment Tool (HEAT) for walking and cycling quantifies health impacts in terms of premature deaths avoided or caused as a result of changes in active transport. This article attempts to assess the effect of incorporating 'life-years' as an impact measure to increase the precision of the model and assess the effect on the tool's usability.
Study design: This article is a methods paper, using simulation to estimate the effect of a methodological change to the HEAT 4.2 physical activity module.
Methods: We use the widely used WHO HEAT for walking and cycling as a case study. HEAT currently quantifies health impacts in terms of premature deaths avoided or caused as a result of changes in active transport. We assess the effect of incorporating "duration of life gained" as an impact measure to increase the precision of the model without substantially affecting usability or increasing data requirements.
Results: Compared with the existing tool (HEAT version 4.2), which values premature deaths avoided, estimates derived by valuing life-years gained are more sensitive to the age of the population affected by an intervention, with results for older and younger age groups being markedly different between the two methods. This is likely to improve the precision of the tool, especially where it is applied to interventions that affect age groups differentially. The life-years method requires additional background data (obtained and used in this analysis) and minimal additional user inputs; however, this may also make the tool harder to explain to users.
Conclusions: Methodological improvements in the precision of widely used tools, such as the HEAT, may also inadvertently reduce their practical usability. It is therefore important to consider the overall impact on the tool's value to stakeholders and explore ways of mitigating potential reductions in usability.

Introduction

There has been an increasing awareness of the need to incorporate Health in All Policies (HiAP) to ensure that non–health government agencies work in partnership to incorporate considerations of health and well-being when developing policy.[1] One simple way in which HiAP is often facilitated is through quantitative Health Impact Assessments (HIA), simple statistical models of the world, which aim to quantify the costs and benefits of interventions.[2,3] To make HIA easier and cheaper to implement, online tools have been developed, which allow stakeholders to undertake their own HIA.[4,5]

The WHO-Europe's Health Economic Assessment Tool (HEAT 4.2) is an example of a widely used HIA tool designed specifically for a HiAP purpose,[1] allowing decision-makers in the transport sector to incorporate the health implications of walking and cycling

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into economic appraisals.[6] The tool has been used directly by public sector decision-makers in different locations, including Kuopio (Finland), Parnu (Estonia), Brighton & Hove (UK), Modena (Italy), and Viana do Castelo (Portugal), and by academics in a number of published studies over the past two decades.[7,8] One of the reasons why the HEAT has been so popular is that it is simple and easy to use, as one of the core principles of the HEAT is to be "as user-friendly as possible".[6]

The HEAT 4.2 has four modules: physical activity, air pollution, crash risk, and carbon emissions.[6] The physical activity module generally accounts for most of the estimated intervention effect.[4,9] Within the physical activity module, the estimated net mortality risk change is valued using the Value of a Statistical Life (VSL), an estimate of the societal willingness to pay for a reduction of one statistical fatality.[10] The measure is commonly used in transport planning.[11,12]

Previous studies have compared the results derived by the HEAT with other HIA tools, such as the Integrated Transport and Health Impact Modelling Tool and Dynamic Modelling for Health Impact Assessment.[13,14] Other studies have assessed the effect of the method used to aggregate benefits within HEAT.[15] However, these comparisons have focused on the effect of the shape of the dose–response relationship between physical activity and health outcomes[13] and the choice of a static vs dynamic modeling methodology.[14] To the best of our knowledge, there are no published studies of the effect of the health valuation method, the valuation of lives saved vs life-years gained, on the results of Health Impact Assessment tools for walking and cycling or physical activity. This paper attempts to fill that gap in the literature.

The VSLY represents society's willingness to pay for reductions in fatality risk, which result in an additional statistical life-year. When using the VSLY reductions in fatality risks, younger populations, with greater expected life-years remaining, are valued more highly than reductions in fatality risks for older populations. When the population affected by a policy is representative of society, valuing premature deaths averted using the VSL and life-years saved using the VSLY are likely, conceptually, to yield similar results. However, when the population is not representative, in terms of age, the two approaches are likely to yield very different results. Attempting to value policies in response to the COVID-19 pandemic made this particularly apparent: multiplying the number of premature deaths averted by the VSL resulted in much higher values than multiplying expected life-years saved by the VSLY since COVID-19 related mortality rates rise super-linearly with age.[16,17] In this article, we argue that the same holds for the HEAT: multiplying premature deaths averted from walking and cycling interventions by VSL is likely to yield different results than multiplying life-years saved by the VSLY if the distribution of age in the intervention group does not match the age distribution implicit in the selected HEAT age group.

We begin by using a simple algorithm to derive estimates of VSLY from the VSL values used by the HEAT. We then compare the results, for the physical activity module of the HEAT, for six hypothetical scenarios using both the VSL and VSLY methods. We focus on how a relatively simple HIA tool, the HEAT, could be adapted to better reflect the age distribution within the active travel population. We also discuss the potential implications of these adaptations on the tool's usability, a core principle of the HEAT,[6] and suggest means by which the tool could remain easy to use.

All data and code (in R software environment) is provided in an open access online repository (https://anonymous.4open.science/r/b1ac653f-7e70-43ab-870c-f3ccc4d63914/).

Methods

Data and measures

This study relies on data used in the HEAT 4.2 and previously described in a study by Kahlmeier et al.,[6] that is, WHO country names, country ISO3 codes, VSL estimates based on the OECD Recommendations on Mortality Risk Valuation in Environment, Health and Transport Policies,[12] and dose–response relationships between walking and cycling and mortality from a study by Kelly et al.[18] This study also makes use of two additional data sets: population estimates and life tables for 2017 from a study by Dicker et al.[19] Table A1 in the supplementary material shows a full list of the variables used in the analysis.

Study design

This paper is a methods paper, using simulation to estimate the effect of a methodological change to the HEAT 4.2 physical activity module.

Analysis

First, we estimate, for each of the 51 WHO European Region countries included in the HEAT tool, the VSLY (in 2015 Euros). We then go on to compare the societal value of premature deaths averted for six scenarios when using the VSLY method, the current HEAT method for the full adult range (VSL-1), stratified by younger vs older adults (VSL-2), and the use of VSL using individual age mortality risks (VSL-55).

Estimating the value of a statistical life-year

The VSL estimate used in the HEAT model is based on a meta-analysis of stated preference studies,[12] in which individuals were asked how much they were willing to pay for a small reduction in mortality risk. The estimates vary considerably between countries, ranging from approximately EUR 143,000 in Tajikistan to almost EUR 7m (2015 values) in Luxembourg. The mean age of participants within the studies in HEAT countries was 50 years. By making the assumptions that (1) the VSL at the age of elicitation is the value derived from future life-years until death and (2) all years are valued equally, it is possible to estimate the VSLY using the equation below. The equation inverts the equations used to calculate the VSL in Annex 1.A1 of the OECD report published in 2012.[12]

$$VSLY = \frac{VSL_{50}}{\sum_{i=50}^{109}\prod_{a=50}^{i} Pr(S)_a \times \frac{1}{(1+r)^{a-50}}} \tag{1}$$

The VSLY is equal to the VSL at age 50 years divided by the discounted expected life-years remaining between age 50 and 109 years, the maximum age in our data. The discounted expected life-years remaining is calculated for each age a, using the probability of survival, Pr(S), to the next birthday, as well as the annual discount rate, r. The VSLY for a country is greater where VSL is greater, annual survival probabilities from 50 to 109 years are lower, or if the discount rate is greater.

The Pr(S) estimates were derived from the Global Burden of Disease Estimates[19] and validated against the UN World Population Prospects life tables.[20] The discount rate, r, was set to zero within this analysis for simplicity because different nations use different discount rates in decision-making. The discounted life-years remaining at each age were validated against the yll package in R.[21]

Estimating monetary benefit using the VSLY

The VSLY method estimates the value of premature deaths averted by (1) estimating the relative risk associated with an intervention, given increases in walking and cycling using a linear dose–response function from;[18] (2) estimating discounted life-years saved, given the relative risk, population age distribution, and baseline mortality rates by age; and (3) multiplying the estimated discounted life-years saved by the VSLY estimate.

The equation is shown below:

$$MB = dLYS \times VSLY \tag{2}$$

Discounted life-years saved (dLYS) can be estimated by multiplying the absolute difference in the relative risk of death (ADRR), estimated using a relative risk function from a study by Kelly et al. (2014), by the age-specific mortality rates MR_i to estimate the effect of an intervention on mortality for the population in each age group pop_i. These changes are then multiplied by discounted expected life-years remaining dLYR_i (itself estimated from Global Burden of Disease life tables) for each age group to give overall discounted life-years saved.

As the absolute difference in relative risk is independent of age, it can be factorized, giving Equation 3 (below) in the case of an intervention affecting 20- to 74-year-olds.

$$dLYS = \Delta RR \times \sum_{i=20}^{74} MR_i \times dLYR_i \times pop_i \tag{3}$$

Inputting this back into our original equation gives:

$$MB = VSLY \times \Delta RR \times \sum_{i=20}^{74} MR_i \times dLYR_i \times pop_i \tag{4}$$

where i has 55 values representing each age from 20 to 74 years.

Note that both VSLY and ADRR are constants while mortality rate, discounted life-years remaining, and population vary with age.

This equation is not substantially more complex than the existing HEAT method (in Equation 5 below), in which monetary benefit is the VSL multiplied by the absolute difference in relative risk associated with an intervention, age group mortality risk, and the number affected.

$$MB = VSL \times \Delta RR \times MR_{20-74} \times pop_{20-74} \tag{5}$$

Comparing four methods for six hypothetical scenarios

To compare the proposed VSLY model with the current HEAT models, we estimate the annual, per capita monetary benefit using four different methods: (1) VSL-1 refers to the current HEAT model with a single mortality rate for the entire population aged 20–74 years, (2) VSL-2 uses the current HEAT model with two mortality rates based on weighted population means (walking: 20–44 and 45–74; cycling: 20–44 and 45–64), (3) VSL-55 uses the existing HEAT model methodology (valuing premature deaths averted using the VSL) but with separate mortality risk estimates for each age from 20 to 74 years, and finally, (4) the VSLY model described previously, using individual ages as in (3) but valuing life-years saved using the VSLY estimates derived earlier. In all cases, the discount rate was set to zero for ease of comparison. We use the four methods to estimate the value of six hypothetical scenarios, three for walking and three for cycling, as shown in Table 1 alongside results for France.

Results

There is considerable heterogeneity in the VSLY estimates of WHO-Europe countries, ranging from EUR 5828 in Kyrgyzstan to EUR 216,838 in Luxembourg, with higher values in western Europe than in eastern Europe. A full table of the VSLY estimates derived are provided in the supplementary material in Table A2 and are broadly aligned with previous estimates of societal willingness to pay for a statistical life-year.[22]

In the first simple scenario, an extra 10-min walking per week for every person aged 20–74 years, the VSLY method results in approximately 25% lower estimated benefits than VSL-1 or VSL-2 (current method with one or two age groups). The effect is not because of more precise mortality rate estimates; the VSL method applied to a population categorized in 1-year age bands (VSL55) results in the same estimates to the VSL model with one and two groups (VSL-1 and VSL-2). Rather, the different estimates for the VSLY are due to assigning our estimates of life-years remaining to each prevented premature death. A full set of results are available in the supplementary material: Table A3 for the three walking scenarios (Scenarios 1, 2, and 3) and Table A4 for the three cycling scenarios (Scenarios 2, 4, and 6).

Fig. 1 displays the results from Scenario 1 graphically for all 51 countries. The current 'best' HEAT method, the VSL with two age groups (VSL-2), is shown on the x-axis as the reference method, and all other methods are depicted in a color-coded scatter plot with a 45-degree line used to depict equity. As these assessments cover the entire HEAT age range (20–74 years), the VSL-1 and VSL-55 estimates are identical to the VSL-2 estimates and therefore lie (jittered) on the 45-degree line. The monetary benefits estimated by the VSLY (blue) are around one-third lower than those estimated by the current VSL-2 model (black line). This is because those with the greatest mortality rates (older people) also have the lowest discounted life-years remaining, thereby reducing the effect that older people have on the mean.

Fig. 1 shows the estimates generated by increased activity in the population aged 20–74 years. However, this masks differences in estimates for the two current HEAT age groups (20–44 and 45–74 years). Fig. 2 depicts the estimates generated by stratifying the analysis to the population aged 20–44 years (left) and 45–74 years (right). In both cases, the VSL55 (green) estimates are equal to the VSL-2 estimates. The VSL-1 (red) method results in higher values when restricting the analysis to younger people and lower values for older people. The VSLY (blue) estimates tend to be greater than that of the VSL-2 in younger people and lower in older people because younger populations have more expected life-years remaining.

Because there are clear differences in the values generated by different methods, and these differences vary between older and younger populations, we also looked at how the valuation methods differ over the life course in an exemplar country. Fig. 3 below shows a comparison of annual monetary benefits per capita (2017 Euro) associated with 10 min/week of additional walking, for each individual age from 20 to 74 years for the Latvian population using the four different models: VSL-1 (red), VSL-2 (black), VSL-55 (green), and VSLY (blue).

The VSL-1 method generates the same results regardless of age, the VSL-2 method generates different results for the population aged 20–44 years to those aged 45–74 years, and the VSLY (blue) and VSL-55 (green) results are similar until around age 55 years, with monetary benefit increasing as age, and therefore, mortality rates increase. However, the VSLY model does not increase as quickly with age because life-years remaining are falling with age also—this is particularly stark from age 60 years onwards.

Finally, it is interesting to observe the differences in results between countries when using the VSLY methods. Fig. 4 shows the estimated per capita annual monetary benefit of an additional 10 min of walking per week per person aged 20–74 years for the HEAT countries on a choropleth map. There are large differences in

Table 1
Monetary benefit estimates for France for each of the six scenarios using the VSL method with two age groups and the VSLY method with individual ages (*assumes scenario population is representative of the general population within that age range*).

Scenario	VSL method result (two groups) in 2017 EUR	VSLY method result in 2017 EUR
Population aged between 20 and 74 do an additional 10 min of walking per week.	86.56	63.75
Population aged between 20 and 64 do an additional 10 min of cycling per week.	77.85	72.5
Population aged between 20 and 44 do an additional 10 min of walking per week.	15.11	21.73
Population aged between 20 and 44 do an additional 10 min of cycling per week.	22.27	32.03
Population aged between 45 and 74 do an additional 10 min of walking per week.	147.27	99.45
Population aged between 45 and 64 do an additional 10 min of cycling per week.	143.42	120.26

VSL, value of statistical life; VSLY, value of statistical life-year.

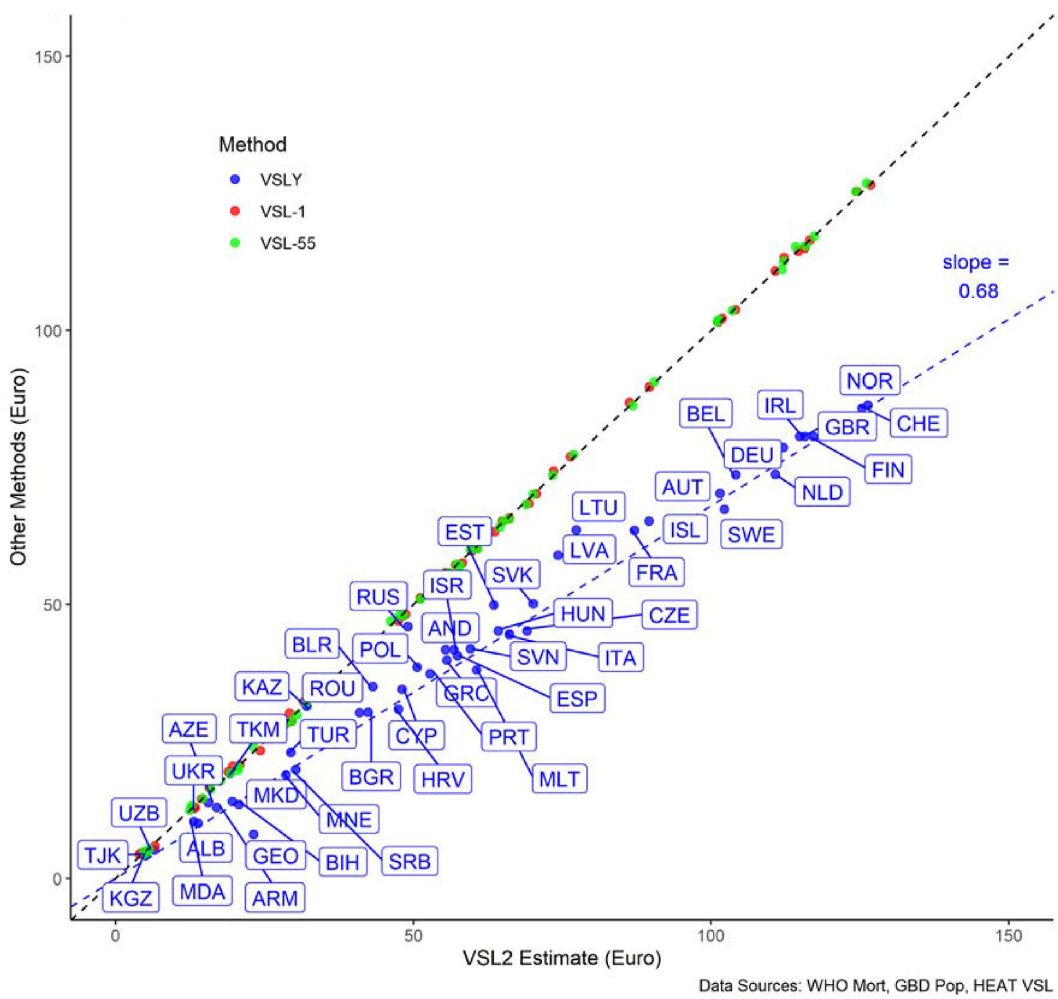

Fig. 1. Estimated annual monetary benefit per capita (in 2017 Euro) in scenario 1, comparing alternative methods to *VSL-2*. VSL, value of statistical life; VSLY, value of statistical life-year; VSL-1, VSL for full adult age range; VSL-2, VSL stratified by younger vs older adults; VSL-55, VSL using individual age mortality risks.

estimated monetary benefit per capita between HEAT countries, with estimated monetary benefit ranging from EUR 4.52 in Tajikistan to EUR 117.13 in Luxembourg.

Discussion

This study is the first to compare the effect of the valuation method used to value averted premature deaths in a Health Impact Assessment tool for physical activity. It uses the WHO HEAT 4.2 for walking and cycling as a case study to compare the estimates of the value of active transport using two different methods: the Value of Statistical Life and the Value of Statistical Life-Year. We show that the VSLY approach generates lower estimates and is more sensitive to differences in the age of the affected population than the VSL with two age groups (VSL-2). However, this comes with a trade-off: although the use of the VSLY may be more accurate, there are additional data requirements of the user. As the minimal data entry requirements of HEAT 4.2 have shown to be a main barrier to wider use of the HEAT, this potential additional user burden warrants serious consideration.

Our findings align with those of previous studies, for example, the work of Robinson et al.,[16] which found that estimates using the VSLY method result in lower valuations of interventions to reduce

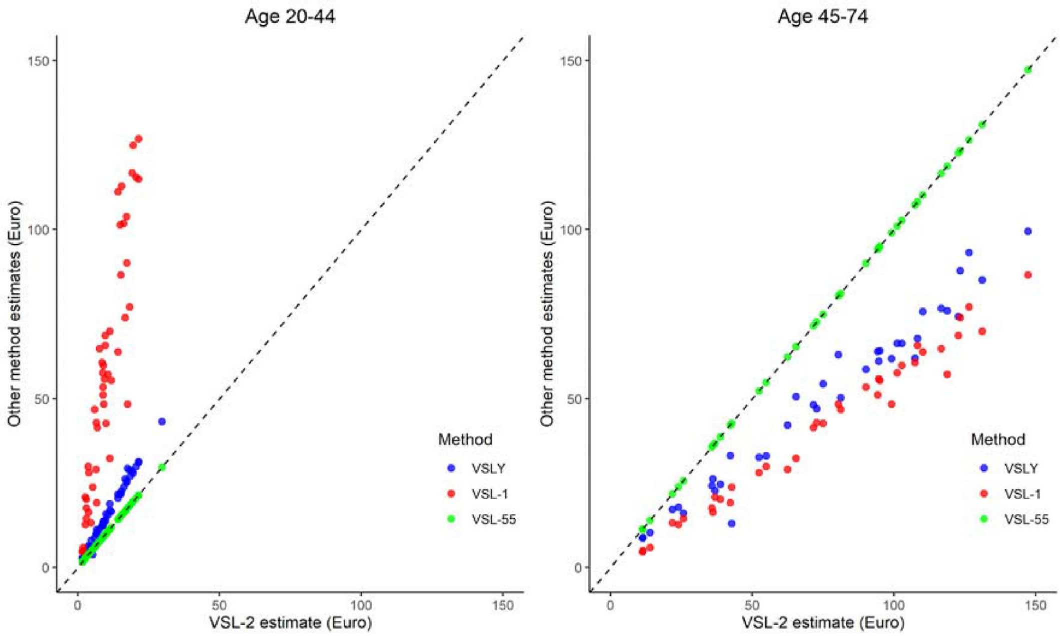

Fig. 2. Estimated annual monetary benefit (in 2017 Euro) per capita from 10-min additional weekly walking using country-specific population age distributions from 20 to 44 years (left) and 45–74 years (right), *VSLY* vs current HEAT models. VSL, value of statistical life; VSLY, value of statistical life-year; VSL-1, VSL for full adult age range; VSL-2, VSL stratified by younger vs older adults; VSL-55, VSL using individual age mortality risks.

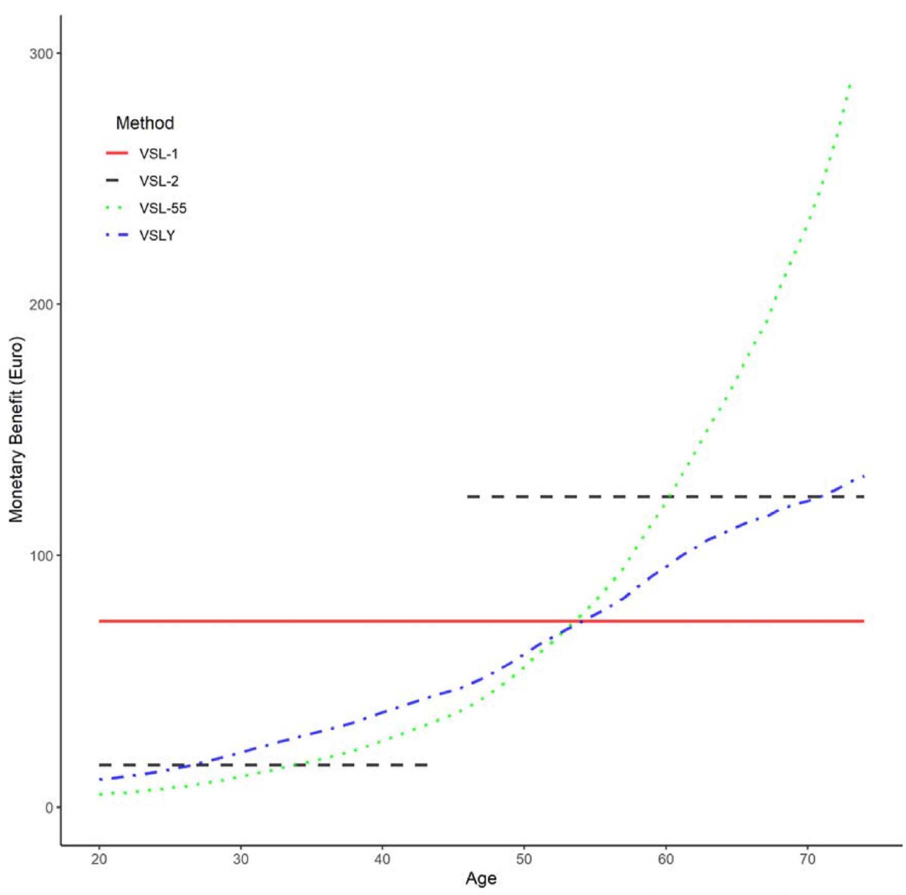

Fig. 3. Annual monetary benefit per capita (in 2017 Euro) from 10-min additional weekly walking for each age of Latvian population, using each method. VSL, value of statistical life; VSLY, value of statistical life-year; VSL-1, VSL for full adult age range; VSL-2, VSL stratified by younger vs older adults; VSL-55, VSL using individual age mortality risks.

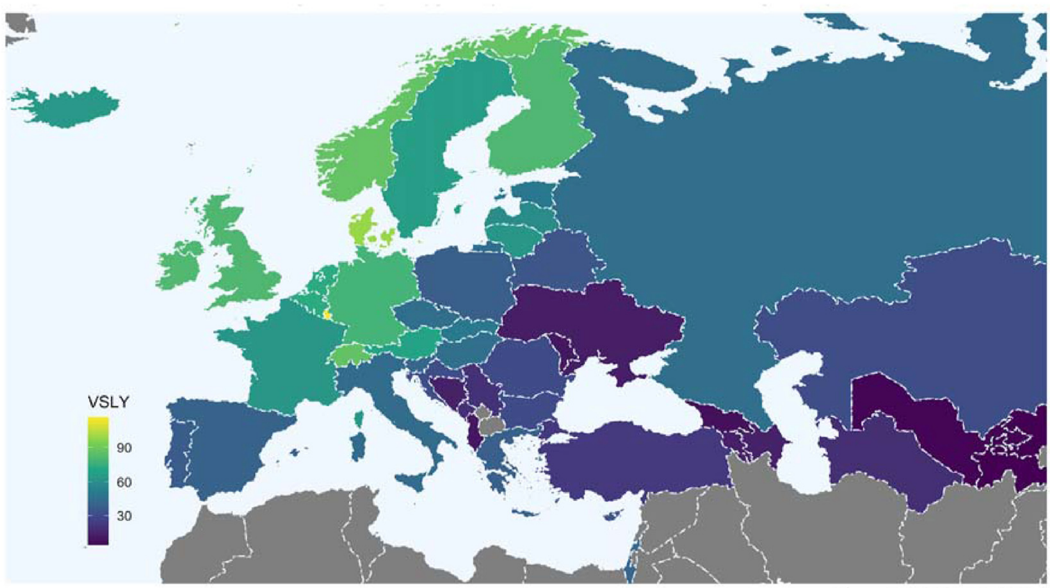

Fig. 4. Map of estimated per capita annual monetary benefit (2017 Euro) of an additional 10 min of weekly walking per person aged 20–74 years for 51 HEAT countries. HEAT, Health Economic Assessment Tool; VSLY, value of statistical life-year.

COVID-19 deaths, primarily from older populations. However, this is the first study that has explicitly analyzed the significance of these methodological decisions for an HIA tool. It is also the first to critique the valuation methods in the physical activity module of the WHO HEAT for walking and cycling. We offer a simple enhancement to the current HEAT physical activity module, which remains within the framework used by transport planners but incorporates the duration of life.

Differences in the estimates using VSL and VSLY methods provoke normative questions about the valuation of premature mortality. The VSL values mortality risk equally irrespective of age, thereby valuing a year of expected life more highly for older persons. On the other hand, the VSLY assigns a constant value to *s* life-year, but, as a result, values mortality risk reduction in younger persons more highly.[17] Transport economics typically uses the former, health economics the latter (and includes quality of life). As an HIA tool used widely in transport planning, the HEAT straddles two fields. The appropriate method may depend on the decision problem itself. Giving the tool user the ability to choose which method they would like to use would be a useful future feature in the tool.

There are several limitations of this study. The biggest perceived challenge to implementing the VSLY in the HEAT is the difficulty users in many countries would face in inputting the age distribution of those affected by an intervention. There is therefore a trade-off between precision and usability in this HIA tool. Potential solutions include (1) using the distribution of age in the general population as a default for the active travel population with the option to manually overwrite or (2) the creation of a bespoke age distribution from user-defined parameters, for example, minimum, maximum, and median age. Although neither of these solutions are perfect, they may provide a compromise between usability and accuracy.

A further challenge exists specifically for the HEAT tool in explaining the VSLY method to stakeholders and users. Transport planners are familiar with the concept of the VSL, but gaining buy-in for the use of the VSLY requires an explanation of how discounted life expectancy is calculated. This is another example of where the adaptation of a widely used tool, already being used by stakeholders to support or inform policy, must be carefully considered even if it is methodologically valid. Over the duration of the HEAT's existence the core team have attempted to achieve balance between complexity and precision on the one hand and usability on the other.[23] However, recent developments in data availability, statistical programming, and web-based user interfaces have made it easier to allow stakeholder engagement in complex models.[24] Therefore, the improvements in the conceptual validity provided by the VSLY method should justify implementation within the global version of HEAT currently under development.

An additional issue for accurate valuation of increased population walking and cycling is that the VSL estimates used (in both the VSL and VSLY methods) are derived from a stated preference study with a median age of 50 years. As VSL has been shown to peak around age 50 years,[11] calculating the VSLY from this figure may result in overestimates. Further research is needed to develop stated preference values that account for the many different factors influencing respondents of different ages.

Conclusion

Our findings suggest that incorporation of duration of life gained into the HEAT is theoretically possible, yields very different results where intervention populations are not representative of overall populations, and is more aligned with guidance from the field of health economics. However, where changes to improve the precision of widely used tools such as the HEAT may also reduce their practical usability, it is important to consider the overall impact on the tool's value to decision-makers and other stakeholders. Thus, it will be important to consider the usability of the modified model in practice in future work.

Author statements

Ethical approval

No ethical approval was required for this simulation study, and all data used are available in the public domain.

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Competing interests

None.

Authors' contributions

R.S. contributed to conceptualization, data curation, formal analysis, investigation, methodology, project administration, software, visualization, and writing, reviewing, and editing the article. C.T. and H.S. contributed to supervision and reviewing and editing the article. T.G. contributed to project administration, methodology, and reviewing and editing the article. S.K. contributed to project administration and reviewing and editing the article. E.G. contributed to supervision and reviewing and editing the article. All authors have fulfilled criteria for authorship.

Data availability

Data & Code: https://anonymous.4open.science/r/b1ac653f-7e70-43ab-870c-f3ccc4d63914/

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2021.03.016.

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