Investment case in adolescents' mental health and non-communicable diseases in Uzbekistan

Akhtem Useinov, MSc., Center for Policy Research and Outreach, Westminster International University in Tashkent, Uzbekistan

Bakhrom Mirkasimov, Ph.D., Business School, Westminster International University in Tashkent, Uzbekistan

ABSTRACT

Objectives: In this study we undertake cost-benefit analysis of adolescents' mental health and non-communicable diseases in Uzbekistan.

Methods: We studied investments in intervention-specific costs using the OneHealth Tool (OHT) and program costs for two health programs – (1) mental, neurological, and substance use (MNS) disorders, and (2) non-communicable diseases (NCDs). We modelled interventions incremental costs and health impacts for 2022-2026, considering 2021 as the baseline year. We calculate benefit-cost ratio (BCR) and return-on-investment ratio (ROI) using selected health impacts and costs, discounted at an annual rate of 3% and expressed in 2021 USD. We also do sensitivity analysis at 5% and 10% discount rates.

Results: Estimated costs to scaling-up interventions between 2022 and 2026 for two health programs were equal to 9.81 million USD. Estimated investments show health life-years gained from scaling-up MNS disorders interventions among adolescents were equal to 15,945. 23,945 healthy life-years were gained from scaling-up NCDs interventions. We find a positive return on

investment for mental health conditions – an average return of 7.66 dollars per dollar invested. For NCDs, we find 11.91 dollars return for each dollar invested.

Conclusions: Although we do not study other important causes of the adolescent burden of disease, such as unintentional injuries, self-harm and interpersonal violence, and transport injuries, our findings cover one of the major causes and show substantial benefits from investing in adolescent health and wellbeing in Uzbekistan.

Keywords: investment case, return on investment, mental health, non-communicable diseases, Uzbekistan.

Acknowledgements

The authors appreciate UNICEF team members, Dr. Olga Kim, Health Officer, who led and coordinated the process and provided technical support. Mr. Saidbek Djurabekov and Mr. Alberto Musatti provided very important feedback and comments that have been crucial to finalize the project report submitted to UNICEF. The study would not have been possible without the robust leadership and technical guidance of Dr. Sufang Guo. The authors appreciate the support of WIUT team members at the early stage of the project Dr. Komiljon Karimov and Dr. Sanjar Djalalov. Special thanks to Dr. Zulfiqar Bhutta for providing a review of this research report and his useful comments. Dr. Randall K. Filer provided important comments and suggestions on the sensitivity analysis of the modelling. Special thanks to Ms. Barbara Forbes for her comments and suggestions on the writing style of the report.

Funding/Support

This research was part of the project to support the allocation of government and other resources for national adolescent health and wellbeing strategy (2022-2026) in Uzbekistan. The strategy has not been published in the same form as when the study was conducted; however, some of its components have been proposed within other health strategies in Uzbekistan. The research was conducted with the support of UNICEF representative office in Uzbekistan.

Availability of data and materials

This research is based on different data sources, including the OHT data and outputs, and complementary data and information to model the interventions specific to this study. The data, data sources, and modelled calculations are available upon reasonable request.

Introduction

Adolescence is a critical time of formative growth and brain development [1]. Behaviours that start in adolescence can determine health and wellbeing for a lifetime. Uzbekistan stands at a window of demographic opportunity [2]. The country's population, although still growing, has stabilized while remaining youthful. Adolescents aged 10-19 years old, represented 5.7 million people or 16.2% of the population in Uzbekistan in 2021. Their health and wellbeing will be critical to reap the full potential of the demographic dividend.

Global mortality rate has fallen for adolescents since 1990, from 12.67 to 7.21 deaths per 1,000 adolescents [3]. In Uzbekistan, this rate is 5.13 which is lower than world average, however higher than in most of the developed world, including the North America and the Western Europe. In Uzbekistan, the leading causes of adolescent disease burden are non-communicable diseases [4]. Although NCD-related mortality rates are substantially low in Uzbekistan, but years of life lost (YLL) attributed to NCD, including mental disorders, and their years lived with disability (YLD) burden are concerning.

Situation analysis report of children and adolescents' health provides a comprehensive study on the progress made and the current state of children and adolescents health in Uzbekistan [5]. The study refers to the survey data conducted in Uzbekistan in 2021-2022 and reports that 12.9 per cent of children aged 5-17 years old experience anxiety, and 3.5 per cent suffer from depression. Another recent study by UNICEF [6] on adolescents' mental health and psychosocial well-being at schools, found that 16 per cent of students experienced social isolation, 15.4 per cent had moderate to severe anxiety, and 9.8 per cent had depression. The most common barriers to adolescents and parents seeking help were linked to stigma and embarrassment, scarcity of information about school psychologists and other community resources for mental health and

psychosocial support, and a lack of trust by both adolescents and their parents regarding psychologists' skills and qualifications [5].

Increased investment in adolescent health programs improves their health and survival in the short term. This leads to better health as adults and the likelihood that the next generations will remain healthy. However, investments in adolescent health will require supporting resources. Understanding the costs and resource implications is crucial to consider the feasibility and affordability of adolescent health programs and services implementation.

Uzbekistan has already been studied in a group of lower middle-income countries to undertake benefit cost analysis of a range of interventions to improve adolescent health [7,8]. The modelled interventions for the period of 2015–2030 show average benefit cost ratio of around 10. Sweeny et al. note their study was conducted as an international exercise to develop an overall estimate of the return on investment, and they encourage countries to replicate their methodology at country-specific investment cases [8]. We aim to do this, with a focus on mental health and NCDs of the adolescents.

NCDs and mental health investment case studies have already been conducted in Uzbekistan targeting the working age population. Farrington et al. find economic losses from NCDs made up 9.3 trillion UZS, which was equivalent to 4.7 per cent of gross domestic product in 2016 [9]. The returns on investment they find range from 0.3 UZS to 64.8 UZS for each 1 UZS invested depending on the intervention periods (2018-2022 and 2018-2032), and the health package interventions, including reduction of salt consumption, tobacco control and alcohol consumption interventions. Chisholm et al. find mental health conditions cost the Uzbek economy an estimated UZS 4.8 trillion, equivalent to 0.98% of its gross domestic product in 2019 [10]. As a result of scaling-up of interventions between 2021–2030 healthy years of life gained equalled for

a total of 377,863. ROIs ranged from 0.8 to 2 for alcohol dependence and psychosis, 5 to 10 for anxiety, depression and universal social–emotional learning programs, and more than 23 for epilepsy treatment.

The study by Farrington et al. [9] focuses on the working-age population and provides specific indicators on alcohol use. Based on the WHO's recent report [11], the proportions of 15-year-olds who had drunk alcohol in the last 30 days equalled 6 per cent in Kazakhstan, 6 per cent in Kyrgyzstan and 1 per cent in Tajikistan. There is no data in the report for Uzbekistan. However, it was mentioned to make tobacco, alcohol, and unhealthy foods less affordable to adolescents in Uzbekistan [5].

There are few existing papers on country-specific investment cases [12], and to our knowledge no existing research in post-soviet and Central Asian countries, except for investment cases conducted by the WHO and UN agencies [9,10,13]. Several country-specific cost analyses and investment cases have been conducted as part of national health strategies [14]. Sheehan et al. provide important summary of literature and methods on economic case for investment in adolescent health and wellbeing [15]. Data and analysis on youth and adolescents, particularly for the Central Asian region, is lacking. We thus aim to contribute to the global discussion on the adolescence, a period of life that is often understudied.

Methods

This research provides a cost-benefit analysis for mental health and NCDs in Uzbekistan, using relevant instruments from the OneHealth Tool for scaling-up health interventions [16]. The analysis includes health and program intervention costs, health impacts, and return on

investment. MNS disorders interventions include - anxiety disorders, basic psychosocial treatment, intensive psychosocial treatment, psychosocial care, alcohol use/dependence, and others[1]. The year 2021 was considered as the baseline year and 2026 as the target year for health interventions in this study. The interventions are scaled up (increasing coverage rates) on average from 7.6% to 28.2% for MNS disorders, and from 7.7% to 35.4% for NCDs.

Healthy years lived measure is used to calculate economic benefits from investing in Mental, neurological, and substance use disorders and NCDs [7,17]. Authors in the previous studies distinguish between the social and economic components of the value of a life-year saved. We multiple the total value of a life year across these two components to 1.5 times GDP per capita. This is made up of a social value equal to 0.5 times the GDP per capita. The economic benefits of increased labor force participation are calculated at 1.0 times GDP per capita.

Costs and benefits are discounted at an annual rate of 3% and expressed in 2021 USD. Particularly, costs are discounted for the period between 2022 – 2026 for all health programs. Benefits for MNS disorders and NCDs expressed in terms of healthy life-years gained are discounted within the period between 2022 – 2026, because the benefits (healthy life-years gained) are aggregated within the given period. We also do sensitivity analysis at 5% and 10% discount rates. Costs from previous years were adjusted to local or international inflation rates, depending on a cost item source and a category[2].

Additionally, Global Burden of Disease data on Disability-adjusted life years (DALYs) was used in an application with human capital models cited in the previous studies to calculate the cost of

[1] The list of the OneHealth Tool and program specific interventions is available in the supplementary materials.
[2] Please refer to the supplementary materials for the detailed methodology on costs, health impacts, benefit-cost and the return on investment.

illness (disease burden) [7]. DALYs data were available by gender and age for specific diseases, including for adolescents, for Uzbekistan. DALYs are calculated as the present discounted value of future years of healthy life lost to morbidity/disability and future years of life lost to premature mortality [18].

The highest causes of health burden among adolescents, in Uzbekistan in 2021, were associated with non-communicable diseases (298,966 DALYs), followed communicable, maternal, neonatal, and nutritional diseases (99,388 DALYs), and by injuries (94,916 DALYs). Mental disorders, neurological disorders, unintentional injuries, nutritional deficiencies, and self-harm and interpersonal violence were the highest disease burden causes among adolescents in Uzbekistan in 2021.

Table 1. Global Burden of Disease data on DALYs (2021)

Cause	DALYs	Share of DALYs
Mental disorders	76,253	15.46
Neurological disorders	49,116	9.96
Unintentional injuries	42,198	8.55
Nutritional deficiencies	38,610	7.83
Self-harm and interpersonal violence	34,551	7.00
Skin and subcutaneous diseases	34,196	6.93
Respiratory infections and tuberculosis	31,284	6.34
Musculoskeletal disorders	30,446	6.17
Other non-communicable diseases	30,209	6.12
Neoplasms	21,234	4.30
Transport injuries	18,166	3.68
Maternal and neonatal disorders	14,257	2.89
Cardiovascular diseases	14,061	2.85
Diabetes and kidney diseases	11,158	2.26

Digestive diseases	10,315	2.09
Sense organ diseases	9,060	1.84
Other infectious diseases	8,622	1.75
Chronic respiratory diseases	7,514	1.52
Substance use disorders	5,405	1.10
Neglected tropical diseases and malaria	4,317	0.88
HIV/AIDS and sexually transmitted infections	1,555	0.32
Enteric infections	743	0.15
Total	493,270	100.00

Source: Global Burden of Disease (GBD)

Following the methods of Brown; and Sachs we calculate disease burden for non-communicable diseases by multiplying annual number of lost life years (DALYs) by a per capita income [19,20]. We use current (2021) GDP per capita rate to evaluate economic losses for a cohort of adolescents living in 2021. Sachs proposed two methods to calculate economic losses of DALYs (1) DALY is valued very conservatively as equal to per capita income, (2) each DALY is valued at three times the per capita income. We report results for both methods [20].

The highest burden (the cost of inaction) is reported for non-communicable diseases, including mental and neurological disorders, which was equal to 592.9 million USD (conservative method) or 1.8 billion USD (alternative method multiplied by 3)[3].

The highest health burden is associated with mental disorders and equalled to 151.3 million USD. Alternatively, for Mental, neurological, and substance use disorders, we model the economic effects of morbidity among adolescents regarding work participation and productivity losses. Impaired productivity losses are calculated with respect to potential absenteeism and

[3] In 2021, the GDP of Uzbekistan equaled 68.54 billion USD.

presenteeism. It is estimated that adults with mental disorders are 4-15 days out of the role per year because of depression and 8-24 days because of generalized anxiety disorders [21]. Moreover, additional time lost per year due to presenteeism was 11-25 partial disability days for depression and 12-26 for generalized anxiety disorders. We estimate annual losses in productivity measured as 5% reduction in working days as a result of absenteeism and a 5% reduction through presenteeism.

We calculate disease burden (cost of illness) for 2703 adolescents who were registered to have mental health disorders, based on the Committee of the Republic of Uzbekistan on Statistics data. Using data on average productivity per employer, average labour force participation rate, productivity growth rate for lower-middle income countries at 2.5% with declining rate to 1.6% over 35 years, and reduction in productivity of 10% due to absenteeism and presenteeism, we calculate indirect costs or cost of illness for mental health disorders among the current cohort of adolescents. The economic burden from decreased labour productivity is estimated at 193 million USD in NPV. If we compare these results to the DALYs burden analysis, Mental disorders and Neurological disorders in sum equalled 248.63 million USD based on the data of 2021.

Results

Based on our estimates, scaling-up of interventions for MNS disorders health program require 4.86 million USD investment. For NCDs program, it is estimated to invest 4.95 million USD. Health gains (impacts) from scaling-up MNS disorders and NCDs interventions show total health life-years gained from scaling-up MNS disorders among adolescents with depression or anxiety

were equal to 15,945, out of which 6,659 healthy life years were attributed to depression disorders. As for NCDs healthy life-years gained from scaling-up are equal to 23,945.

Table 2. Cost-benefit results from scaling-up interventions

Healthy years lived gained from interventions	2022	2023	2024	2025	2026	*Total*
Depression	380	833	1313	1810	2323	6659
Anxiety	187	503	902	1349	1814	4755
Epilepsy	50	151	299	495	734	1729
Alcohol use	136	328	544	776	1018	2802
Total MNS	753	1815	3058	4430	5889	15945
NCDs	1484	3051	4706	6445	8259	23945
Intervention costs						
Depression	$0.13	$0.22	$0.32	$0.41	$0.49	$1.56
Anxiety disorders	$0.14	$0.24	$0.35	$0.45	$0.54	$1.71
Epilepsy	$0.08	$0.13	$0.18	$0.23	$0.28	$0.90
Alcohol use	$0.06	$0.10	$0.14	$0.17	$0.21	$0.69
Total MNS	$0.40	$0.70	$0.99	$1.26	$1.52	$4.86
NCDs	$0.99	$0.99	$0.99	$0.99	$0.99	$4.95
Monetized benefits						
Depression	$1.10	$2.34	$3.57	$4.78	$5.96	$17.75
Anxiety disorders	$0.54	$1.41	$2.46	$3.57	$4.65	$12.63
Epilepsy	$0.14	$0.42	$0.81	$1.31	$1.88	$4.57
Alcohol use	$0.39	$0.92	$1.48	$2.05	$2.61	$7.46
Total MNS	$2.17	$5.09	$8.32	$11.71	$15.11	$42.41
NCDs	$4.29	$8.56	$12.81	$17.03	$21.19	$63.88
Benefit-cost ratio						
Depression	8.72	10.46	11.28	11.77	12.11	11.35

Anxiety disorders	3.96	5.77	7.06	7.99	8.64	7.37
Epilepsy	1.85	3.23	4.47	5.68	6.82	5.09
Alcohol use	6.15	8.99	10.63	11.75	12.55	10.83
Total MNS	5.38	7.26	8.44	9.31	9.97	8.72
NCDs	4.33	8.65	12.95	17.22	21.42	12.91
Return on investment						
Depression	$7.72	$9.46	$10.28	$10.77	$11.11	$10.35
Anxiety disorders	$2.96	$4.77	$6.06	$6.99	$7.64	$6.37
Epilepsy	$0.85	$2.23	$3.47	$4.68	$5.82	$4.09
Alcohol use	$5.15	$7.99	$9.63	$10.75	$11.55	$9.83
Total MNS	$4.38	$6.26	$7.44	$8.31	$8.97	$7.72
NCDs	$3.33	$7.65	$11.95	$16.22	$20.42	$11.91

Source: Authors` calculations

Estimated monetized gains from scaling-up interventions equal 42.41 million USD for MNS disorders and 63.88 million USD for NCDs.

Estimations on costs and monetized health impacts enable us to calculate return on investment. We find positive return on investment for each mental health condition: 10.35, 6.37, 4.09 and 9.83 dollars return for each dollar invested for depression, anxiety, epilepsy and alcohol use, respectively. For NCDs, we find 11.91 dollars return for each dollar invested.

The above results are based on 3% discount rate. Results at 5% and 10% discount rates show similar results.

Table 3. Cost-benefit results at 5% and 10% discounted

	Discount rate 5%		Discount rate 10%	
	Benefit to cost ratio	Return on per 1 USD of investment	Benefit to cost ratio	Return on per 1 USD of investment
MNS disorders				
Depression	11.32	11.32	11.24	10.24
Anxiety	7.33	6.33	7.24	6.24
Epilepsy	5.05	4.05	4.94	3.94
Alcohol use	10.77	10.77	10.62	9.62
NCDs	12.6	11.63	12.0	11.00

Source: Authors` calculations

Discussion

Uzbekistan has the potential to reduce the socioeconomic burden of adolescent health conditions through a set of evidence-based interventions. Targeting universal health coverage, Uzbekistan should ensure that adolescent health services, including mental health and NCDs services are accessible and covered at the national level.

By acting now, Uzbekistan can reduce the burden of adolescent health conditions. The findings of the investment case using the OHT demonstrate that investing in adolescent health interventions over the period between 2022 and 2026 has a positive return on investment, and the results allow decision-makers to consider the feasibility and affordability of the implementation plan. Health and program interventions implemented jointly would reduce adolescent disease burden, depending on the coverage and effectiveness of interventions.

The benefits to costs and ROI results of our study are similar to the previous studies conducted at regional level and for Uzbekistan [7,10]. Average benefit to cost ratios modelled for adolescent interventions in lower-middle income countries were equal to 9.9 [7]. In the mental health study, Chisholm et al. found benefit to cost ratios amount to 2.3–3.0 to 1, when economic benefit is only were considered, and 3.3–5.7 to 1 when the value of health returns is also included [21]. Chisholm et al. found school based social–emotional learning (SEL) programs targeting adolescents were costed have 7.9 net returns on investment, with 1205 UZS (around 0.1 USD) per capita costs to scaled-up school based SEL interventions over 2021-2025 [10].

A systematic review of health economic evaluations of universal mental health interventions for children and adolescents aged 6–18 years show most interventions in the review were school based, suggesting schools are considered an appropriate setting for improving and protecting children and adolescents' mental health [22]. Schools should be supported in the implementation of long-term anti-bullying programs for children and adolescents and promotion of social and emotional well-being programs.

Limitations

Some direct and indirect benefits from the interventions modelled within the OHT could be omitted. For example, we do not estimate benefits of health life years gained on education attainment, rather directly value these benefits in terms of GDP per capita. Cost-effectiveness methods in healthcare policy such as cost-effectiveness thresholds require estimations using real-world evidence, separating it from the rule of one to three times the gross domestic product per capita [23]. The methodology thus could be developed in further research.

As most of the costing studies conducted previously, this study follows a number of different assumptions, including within the OHT and other settings in the models developed. Relying on the assumptions of compartmental models, such as those implemented in the OHT, does not allow for the same level of accuracy as agent-based microsimulation models, and they should ideally be complemented by stochastic uncertainty analysis [24].

Moreover, not all default interventions used within the context of the OHT could be relevant to Uzbekistan. Some health services could be not available in the health sector, or on the other hand, the OHT could not include services available for Uzbekistan. Policy makers and other stakeholders can use this study to produce a first rough assessment of the feasibility of interventions. But actual policymaking has to be assisted with much more detailed costing and impact analysis for each intervention by each program administrator.

References

1. The Lancet. Our future Invest in adolescent health now. 2017. https://www.thelancet.com/pb-assets/Lancet/stories/our-future/index.html
2. UNICEF. *Generation 2030 Uzbekistan Investing in Children and Young People to Reap the Demographic Dividend*. 2018.
3. UNICEF. Mortality among children, adolescents and youth aged 5–24. 2023. https://data.unicef.org/topic/child-survival/child-and-youth-mortality-age-5-24/
4. UNICEF. Adolescent Data Portal. Uzbekistan. 2019. https://data.unicef.org/adp/country/uzb/
5. UNICEF. *Situation Analysis of Children and Adolescents in Uzbekistan*. 2024. Accessed March 25, 2025. https://www.unicef.org/uzbekistan/en/media/6731/file/SitAnen.pdf.pdf

6. UNICEF. *Adolescents' Mental Health and Psychosocial Well-Being at Schools*. 2022. Accessed March 25, 2025. https://www.unicef.org/uzbekistan/en/reports/adolescents-mental-health-and-psychosocial-well-being-schools

7. Sheehan P, Sweeny K, Rasmussen B, et al. Health Policy Building the foundations for sustainable development : a case for global investment in the capabilities of adolescents. *The Lancet*. 2017;390(10104):1792-1806. doi:10.1016/S0140-6736(17)30872-3

8. Sweeny K, Friedman HS, Sheehan P, Fridman M, Shi H. A Health System e Based Investment Case for Adolescent Health. *Journal of Adolescent Health*. 2019;65(1):S8-S15. doi:10.1016/j.jadohealth.2019.03.023

9. Farrington J, Kontsevaya A, Small R, et al. *Prevention and Control of Noncommunicable Diseases in Uzbekistan The Case for Investment*. 2018. https://www.who.int/uzbekistan/publications/m/item/prevention-and-control-of-noncommunicable-disease-in-uzbekistan.-the-case-for-investment-(2018)

10. Chisholm D, Kontsevaya A, Dombrovskiy V, Stanton R, Ho M, Grafton D. *Prevention and Management of Mental Health Conditions in Uzbekistan The Case for Investment*. 2021.

11. Charrier L, et al. *A Focus on Adolescent Substance Use in Europe, Central Asia and Canada. Health Behaviour in School-Aged Children International Report from the 2021/2022 Survey. Volume 3*. 2024. Accessed June 8, 2026. https://iris.who.int/items/ad14f809-aa5e-4db7-a37f-ceb72963cdf3

12. Hutchinson B, Small R, Acquah K, et al. The investment case as a mechanism for addressing the NCD burden: Evaluating the NCD institutional context in Jamaica , and the return on investment of select interventions. *PLoS One*. 2019;14(10):1-11.

13. Kontsevaya A, Farrington J, Kulikov A, Rotar O, Webb D. *Prevention and Control of Noncommunicable Diseases in Kyrgyzstan The Case for Investment*. 2017.

14. Avenir Health. OneHealth Tool Country Applications. https://www.avenirhealth.org/software-onehealthcountries.php

15. Sheehan P, Rasmussen B, Sweeny K, et al. *Adolescent Well-Being: Background Papers for Multi-Stakeholder Consultations*. 2021. https://pmnch.who.int/resources/publications/m/item/the-economic-case-for-investment-in-adolescent-wellbeing

16. Avenir Health. OneHealth Tool. https://www.avenirhealth.org/software-onehealth.php

17. Stenberg K, Axelson H, Sheehan P, et al. Advancing social and economic development by investing in women's and children's health: A new Global Investment Framework. *The Lancet*. 2014;383(9925):1333-1354. doi:10.1016/S0140-6736(13)62231-X

18. Larson BA. Calculating disability adjusted-life-years lost (DALYs) in discrete-time. *Cost Effectiveness and Resource Allocation*. 2013;11(18).

19. Brown DW. Economic value of disability-adjusted.pdf. *Rev Panam Salud Publica*. 2008;24(3):203-209.

20. Sachs JD. *Macroeconomics and Health: Investing in Health for Economic Development*. 2001. doi:10.1038/nm0602-551b

21. Chisholm D, Sweeny K, Sheehan P, et al. Scaling-up treatment of depression and anxiety: A global return on investment analysis. *Lancet Psychiatry*. 2016;3(5):415-424. doi:10.1016/S2215-0366(16)30024-4

22. Schmidt M, Werbrouck A, Verhaeghe N, Putman K, Simoens S, Annemans L. Universal Mental Health Interventions for Children and Adolescents: A Systematic Review of Health Economic Evaluations. *Appl Health Econ Health Policy*. 2020;18(2):155-175. doi:10.1007/s40258-019-00524-0

23. Espinosa O, Rodríguez-Lesmes P, Romano G, et al. Use of Cost-Effectiveness Thresholds in Healthcare Public Policy: Progress and Challenges. *Appl Health Econ Health Policy*. 2024;22(6):797-804. doi:10.1007/s40258-024-00900-5

24. Chisholm D, Lee YY, Meheus F, Kulikov A. Making the Investment Case for Mental Health in Low- and Middle-Income Countries. *Value Health Reg Issues*. 2025;48:101132. doi:10.1016/j.vhri.2025.101132