Perspectives in Public Health

- A digital campaign to increase awareness of alcohol-exposed pregnancy
- Student mental health - a public health challenge?
- COVID-19, physical distancing, and young adults living alone
- Using consensus methods to develop a Social Prescribing Learning Needs Framework for practitioners in Wales

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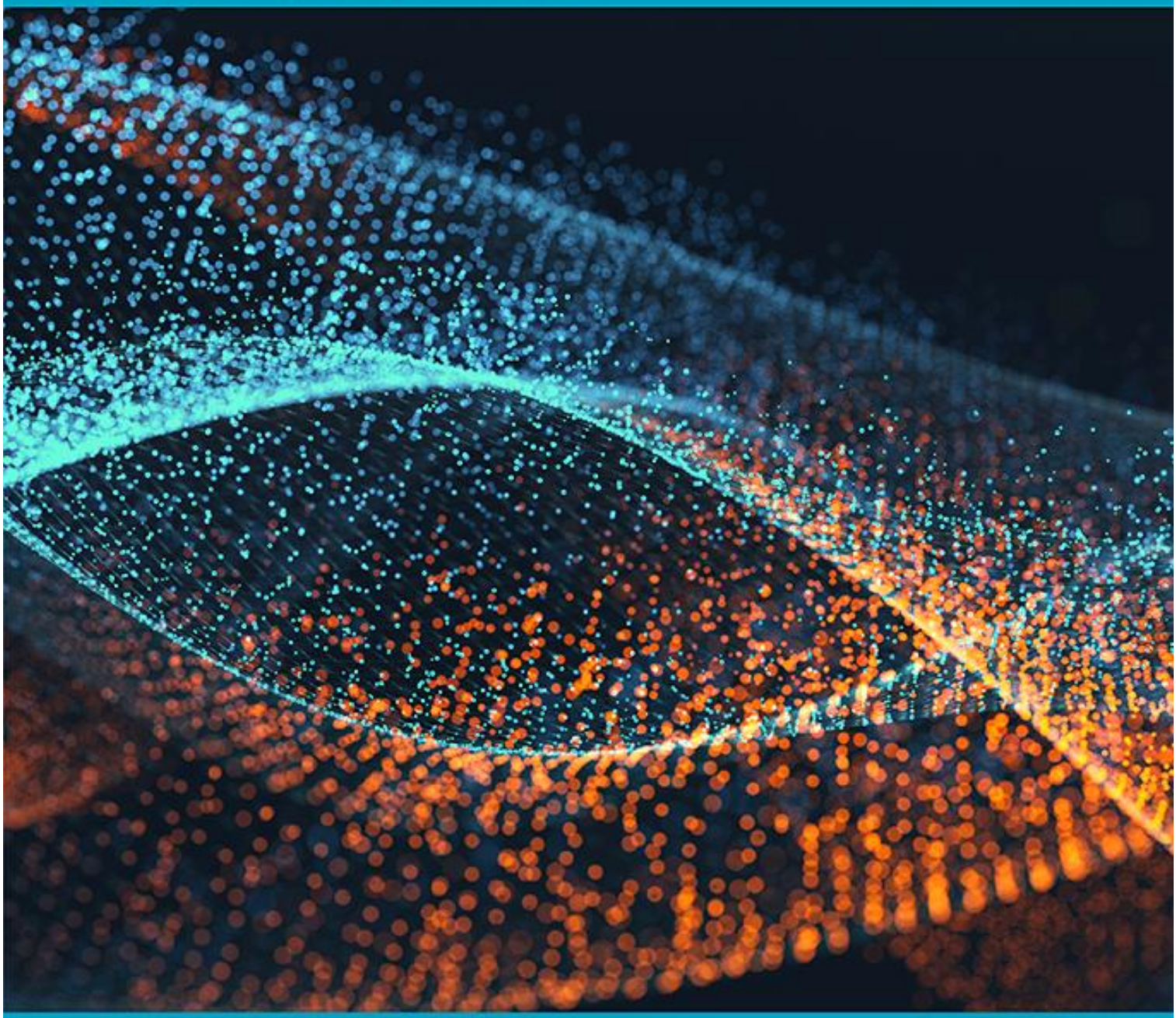

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EDITORIAL

Editorial

Joanna Saunders
Honorary Editor, Perspectives in Public Health

This is my first editorial since taking on the role of Honorary Editor of Perspectives in Public Health (PPH), and I'd like to begin by thanking Dr Ros Stanwell-Smith for her service as both Editor and Deputy Editor over the time that I've been involved in the Editorial Board. Her expertise and experience has been invaluable to us, and in particular to me, as her wealth of knowledge of editing journals has been so useful. PPH has been really successful in increasing its Impact Factor and reach over the years with some very highly cited papers from internationally known authors. However, the day-to-day work in producing six issues each year is undertaken by our talented editorial team and members of the editorial board, and I'm very grateful to them all.

We have seen a significant rise in submissions to PPH over the past year, with many submissions on the topic of Covid-19. Many of these were not accepted for publication – either because they date very quickly or are not written for our audience. However, we have seen some reflective pieces including the paper by Richard Armitage on Covid-19, physical distancing and young people living alone – a particular concern for those of us working in universities, where we are not able to provide pastoral support in the traditional ways to students who may be living away from home for the first time. Baber and Bate provide further insight into the mental health and wellbeing of students, and the importance of preparation for a more independent life, both in terms of learning and social relationships, but also in relation to the understanding and management of feelings and emotions which come with independence.

The paper by Burns and Van Der Meer looks at the role of crafting (in this instance crochet) to increase relaxation and reduce stress. There is much anecdotal evidence of the positive effects of crafts on mental wellbeing, but this study, with a sample of over 8,000 individuals living in 87 countries, shows positive benefits for personal wellbeing, with respondents using crochet to manage mental and physical health conditions and life events.

Social prescribing programmes frequently include arts and crafts within their offer and there have been a number of evaluations of the impact of commissioned social prescribing programmes, albeit a significant number with insufficient rigour or comparative outcomes.[1] At the same time, there has been limited consensus on the learning, training and education needs of those delivering social prescribing. Wallace et al. developed an education and training needs conceptual framework for social prescribers in Wales, for use by commissioners and providers in developing the curricula for social prescribing workers. The study found that elements of the framework which were considered very important for social prescribers were not currently part of their training, and the framework will be used to support the commissioning and decommissioning of training for these workers.

Other peer review papers in this issue include a systematic review which seeks to analyse the evidence of the impact of socioeconomic position on non-communicable diseases (Lago-Penes et al.) and a study tracking changes in demographic characteristics of homeless adult populations which highlights the clinical needs of ageing homeless populations (Tsai et al.). Shorter pieces include a paper considering the use of routine health data for evaluations (Watson-Grant et al.) and the development and testing of a digital campaign to increase awareness of alcohol-exposed pregnancy (Reynolds et al.). #Drymester was delivered across parts of Greater Manchester and has the potential for extended use following evaluation.

Reference

1. Bickerdike L, Booth A, Wilson PM *et al*. Social prescribing: less rhetoric and more reality. A systematic review of the evidence. *BMJ Open* 2017;**7**:4 Available online at: https://bmjopen.bmj.com/content/7/4/e013384.abstract (last accessed 22 February 2021).

cpd ARTICLE

The March 2021 CPD paper was 'To HIIT or not to HIIT? The question pregnant women may be searching for online: a descriptive observational study' by TS Nagpal et al.

Answers: 1c, 2a, 3c, 4d

sustainability

MDPI

Article

College Teaching Innovation from the Perspective of Sustainable Development: The Construction and Twelve-Year Practice of the 2P3E4R System

Na Li [1], Ping Jiang [1], Cuihong Li [1] and Wei Wang [1,2,*]

[1] School of Civil Engineering, Shaoxing University, Shaoxing 312000, China; lina@usx.edu.cn (N.L.); jiangping@usx.edu.cn (P.J.); lich@usx.edu.cn (C.L.)
[2] Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576, Singapore
* Correspondence: wellswang@usx.edu.cn

Abstract: It is imperative to construct high-level, innovative and challenging courses in the teaching of colleges and universities. It is also of great significance to explore innovative teaching methods for improving students' learning effect. In this paper, the course "Civil Engineering Construction" of a civil engineering major is taken as a reform example. In this teaching-innovation mode, guided by students' moral education and students' achievements, and the course platform is built in order to achieve the education concept of sustainable development and cultivate applied talents who can solve complex problems in civil engineering. In teaching practice, "Dual Platforms", which combines course teaching platform and virtual simulation platform, is built mainly to expand the learning approaches. The "Three Educations" mode, which combines on-site education, classroom education, and mental health education, is established to improve the comprehensive quality of students. Comprehensive academic evaluation is carried out through "Four Reports", including an open assignment report, special technical study report, BIM (building information modeling) technical work report, and final comprehensive written test report. Through studying this course, students not only master the knowledge of civil engineering construction, but also acquire knowledge-innovation ability, such as thesis publication, patent writing, discipline competition, and cultivating the craftsman spirit and social responsibility to abide by professional ethics in future work. This teaching innovation mode has been implemented for 12 years and achieved excellent results in cultivating students' intelligent ability for sustainable development. It has been promoted in 14 courses, and has certain reference significance for engineering-course teaching.

Keywords: teaching innovation; virtual simulation; sustainable development; mental-health education

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1. Introduction

As an agreement for the mutual recognition of engineering-education undergraduate degrees, The Washington Accord aims to promote the mutual recognition of engineering degrees and international mobility of engineering technicians through multilateral recognition of engineering education qualifications. Engineering-education quality standards are the core of engineering-education accreditation and the basis for the mutual recognition of academic qualifications. According to The Washington Accord, colleges and universities should track and evaluate students' performance in the entire learning process, regularly carry out course-system setting and quality evaluation, and establish an evaluation mechanism for the achievement of graduation requirements. Course setting should be designed to effectively support the achievement of graduation requirements, and the course-system design must involve the participation of enterprise or industry experts. It is necessary to set up a complete teaching system, and cooperate with enterprises to carry out practice and training, and cultivate students' practical ability and innovation ability, as well as

students' engineering awareness, collaborative spirit, and ability to comprehensively apply the knowledge they have learned to solve practical problems. Therefore, course teaching needs to innovate the aspects of teaching-platform construction, mental-health and professional-spirit education, and process assessment, to evaluate students in a holistic way.

In recent years, China has actively and effectively promoted teaching innovation in colleges and universities. In June 2018, Minister Chen Baosheng of the Ministry of Education proposed for the first time, at the National Conference on Undergraduate Education in Colleges and Universities in the New Era, that we should effectively "increase the burden" on college students, improve their academic challenge, reasonably increase the difficulty and expand the depth of courses. In 2018, 40 articles of higher education in the new era opened a new chapter in promoting a revolution in classroom teaching. Then, in 2019, the quality of undergraduate education reform was 22 articles, and the "Double Ten-Thousand Plan" for the construction of national and provincial first-class courses was put forward. Education informatization has become an indispensable means, and virtual simulation technology has opened up a new path for teaching reform with the advantages of intuitiveness, operability and repeatability. Virtual-simulation teaching can enable students to carry out safe and economically repeatable simulation practice operations in an open, independent and interactive virtual environment, helping students to deeply understand the complex construction technology and professional norms of civil engineering, and effectively improving teaching efficiency and teaching effect. With the rapid development of the marketization of construction industry and building information technology, the business scale and demand on civil engineering construction management are also rapidly expanding, and the demand for improving work efficiency, reducing error rates, and improving construction management quality and information management and utilization, are also increasing [1]. Under such a new situation, the teaching content and teaching mode of courses should closely follow the development of industry, adapt to the requirements of revolutionary changes in methods of knowledge acquisition and teaching under the condition of informatization, and deepen the deep integration of information technology and education and teaching, so as to meet the high goals and high requirements of the new era and new engineering.

In December 2017, the General Office of the State Council issued "Several Opinions on Deepening the Integration of Industry and Education", comprehensively implementing the overall goal of "school–enterprise cooperative education". In 2018, the Ministry of Education launched the industry–university cooperative education project, which aims to promote the reform of talent training in colleges and universities with the latest needs of industrial and technological development. At present, the emergence of new concepts in BIM (building information modeling), prefabrication and other industries has brought challenges to students' learning and application of knowledge on courses, as well as challenges to teachers' teaching. How to use the OBE (outcome-based education) teaching concept to realize the cultivation of new engineering talents, how to integrate the emotional-value goals of the course into industry–university cooperation, and how to achieve university teaching innovation from the perspective of sustainable development, are worthy of our in-depth consideration.

2. Literature Research

Many scholars have conducted in-depth research on this subject. Lee [2] proposed one kind of augmented-reality learning method and conducted an experiment to test its effect. The results show that the use of augmented reality not only effectively improves students' self-efficacy, but also reduces their cognitive load. The implementation of augmented-reality technology in certification courses is conducive to learning outcomes.

Deng's research [3] acknowledged that students' self-evaluation is an important alternative outcome measure in massive open online courses, and emphasized that the careful design of teaching conditions can give learners some psychological challenges and stimuli, which is more conducive to their comprehensive understanding of the content.

Konrad [4] reported that diverse interactions among students, instructors, stakeholders, and mentors are more conducive to cultivating students' key competencies in sustainable development. Using this approach, course instructors can consciously use interaction with students, instructors, stakeholders, and mentors in project-based sustainability courses to cultivate students' ability to cooperate successfully in teams and with stakeholders.

Sanchez-Almeida and Sandoval Palis [5] adopt the method of factor analysis and principal component extraction, and consider four factors: teaching development and planning, teacher–student relationship, evaluation and global evaluation, and propose a university-teaching evaluation process for higher education systems.

Formative assessment and cooperative work are teaching methods based on peer support to promote students' learning. They can not only solve problems, but also identify errors through feedback. Revilla Cuesta [6] analyzed the practical experience of 49 students majoring in mechanical engineering at Burgos University in a technical discipline. The results show that these teaching methods are particularly conducive to promoting autonomous learning, cultivating teamwork skills, and cultivating engineers with correct knowledge and skills for today's world.

"Civil Engineering Construction", as the first stage of the professional-practice ability, has become the first choice of teaching-mode innovation for the civil engineering major. In order to realize the effective innovation and application of the course teaching mode, we carried out a lot of active exploration. This paper will take the course "Civil Engineering Construction" of the civil engineering major as an example to discuss and analyze the student-centered teaching innovation method and practice of the "Dual Platforms, Three Educations, Four Reports", namely, **2P3E4R system**, providing an important reference for engineering courses teaching.

3. Basic Information of the Civil Engineering Construction Course

3.1. Main Content

Shaoxing University aims to build a high-level application-oriented university with distinctive characteristics based in Zhejiang, and cultivate high-quality applied talents with a high sense of responsibility, solid professional knowledge and skills, and the ability to creatively solve complex practical problems in their major. The training goal of the civil engineering major is to cultivate senior applied talents who can creatively solve complex engineering and technical problems in the fields of civil-engineering survey, design, and construction with information technology.

According to the university's orientation and professional training objectives, the "Civil Engineering Construction" course is the core course of civil engineering major, with 56 credit hours and 3.5 credits. It is recommended for students to take it in their fifth semester at the university. The course mainly explores the main types of construction technology and methods in civil-engineering construction, the development and application of new technologies, new materials, and new processes in construction, as well as the scientific and reasonable organization principles and methods of construction projects. It contains 12 chapters in two parts: civil engineering construction technology and construction organization. Construction technology, specifically, includes: earthwork, foundation engineering, masonry engineering, concrete engineering, decoration engineering, waterproofing engineering, installation engineering, building industrialization, bridge engineering, and road engineering. Construction organization, specifically, includes: construction organization principle, construction network plan. In recent years, we have reconstructed and divided the course content to be task driven, and the basic content and teaching requirements are shown in Figure 1.

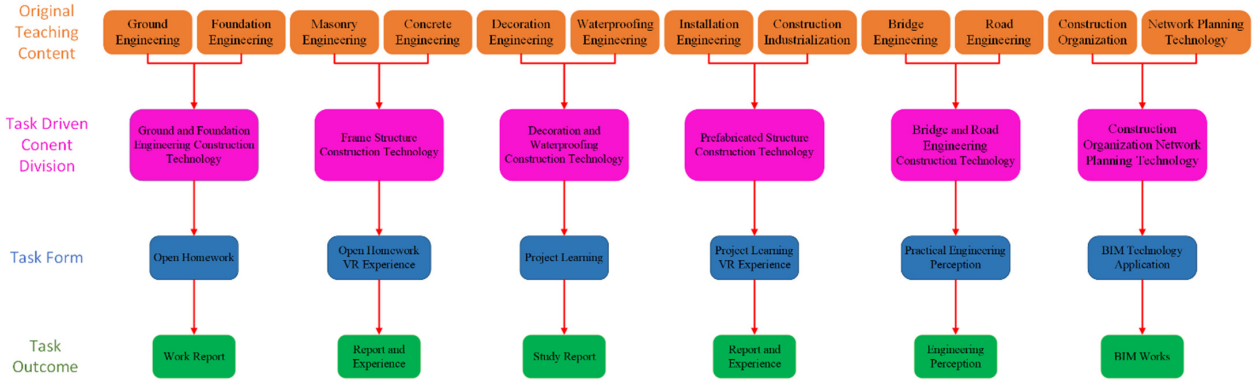

Figure 1. Restructuring diagram of course content to be task driven.

3.2. Main Objectives

The role of the instructor is to promote learning, not to provide knowledge by presenting solutions. Taking the construction technology of Tishk International University as an example, Shareef [7] proposed a teaching/learning framework based on problem-based learning (PBL), a constructivist teaching method and design, so that students can learn technology courses in a way that promotes sustainable and autonomous learning. The results show that, through a variety of teaching methods including autonomous learning, the problem of unclear definitions is solved, and the fun of learning various subjects is improved. This approach provides students with technical knowledge and enables them to benefit from a sustainable learning experience and professional life after graduation.

Combined with the university's orientation and professional-talent training requirements, with the focus on cultivating students' professional ability for sustainable development, the objectives of this course mainly include the following three points.

(1) Knowledge objective. Students are able to use the basic principles of civil-engineering construction to select construction methods suitable for project characteristics and innovate construction techniques; in addition, they can use new network-planning techniques and optimization theories to creatively design the construction organization of engineering projects.
(2) Ability objective. Students shall have the ability to use the theoretical knowledge of construction to solve technical problems encountered in the project construction site, have the ability to use information management tools for construction organization and have the ability to continuously innovate in engineering construction.
(3) Emotional value objective. Students shall have a healthy psychological quality and a sense of social responsibility, have excellent moral quality in work and life, and can carry forward the ultimate craftsman spirit in construction technology and management [8].

3.3. Course Development and Effectiveness

In the course of development, this course has been continuously improved, with a variety of achievements during each stage and large-scale improvement in the course level, creating a high-quality engineering-education learning community that integrates professional education and mental-health education. This course won the school-level key construction course in 2010, the municipal-level excellent course in 2016, the provincial-level first-class course and the collaborative education project of the Ministry of Education in 2019, and the second prize in the Teacher Teaching Innovation Competition of Zhejiang Province in 2021. The course teaching team has won the award of Excellent Grassroots Teaching Organization. The main development process of this course is shown in Figure 2, indicating that the curriculum construction system has experienced continuous improvement for 12 years from 2010 to 2021.

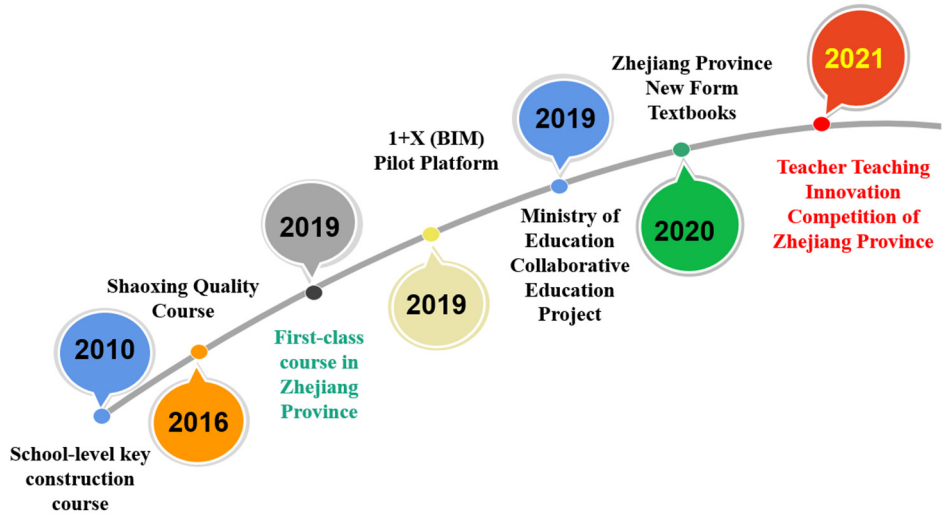

Figure 2. Course innovation and development process.

4. Analysis of Teaching Pain Points and Countermeasures

4.1. Teaching Pain Points

(1) Teaching mode. The construction technology of civil engineering is relatively abstract and the industry is developing rapidly. There is a lag in the integration of cutting-edge technologies into classroom teaching. The traditional teaching mode is insufficient in terms of personalization and innovation, and cannot well support the new engineering goal of cultivating students' ability to solve complex engineering problems.

(2) Students' active-learning ability. Students are mostly passive learners and lack the ability to effectively use all-media three-dimensional teaching resources for active learning, and their self-improvement ability needs to be strengthened.

(3) Students' engineering-thinking ability. Due to a lack of synergy between out-of-class practice and in-class teaching, students' actual perception of the construction process is insufficient and their practical ability is weak. Therefore, students' engineering-thinking ability needs to be further strengthened.

4.2. Countermeasure Analysis

Huang [9] developed the "virtual reality welding course" with students as the main participants, and implemented experimental teaching during a case study with 34 first-year students, with electric welding practice as the research object. The results showed that most students expressed positive affirmation for the learning effect of the virtual-reality-assisted welding course, and their final examination scores at welding practice were significantly higher than those of a mid-term examination. Therefore, virtual reality is an effective method to solve the problem. The main countermeasure of this study is listed as:

(1) A virtual simulation platform and construction-site learning can help to solve the problem of students' weak practical ability.

(2) We help students to form a good knowledge system and professional ethics and a craftsman spirit through activities such as industry elites entering the classroom, team learning, and open assignments.

(3) Through project studies, submitting BIM technical team tasks and other activities, students will have the ability to innovate in civil-engineering construction technology and management.

5. Innovative Thinking and Teaching Practice

5.1. Innovative Thinking

With moral education as the foundation, as well as being student-centered and achievement-oriented, the course platform was built according to the FD-QM (Fudan

University-Quality Matters) standard to realize the integration of practice base, classroom teaching and mental health, so as to cultivate applied talents with sustainable professional ability to solve complex problems in civil engineering. It adopts "Dual Platforms" to expand learning methods, "Three Educations" to improve comprehensive quality, "Four Reports" to carry out comprehensive academic evaluation, and practices a teaching mode that is "high-level, innovation, challenging". The innovative thinking of the course is shown in Figure 3.

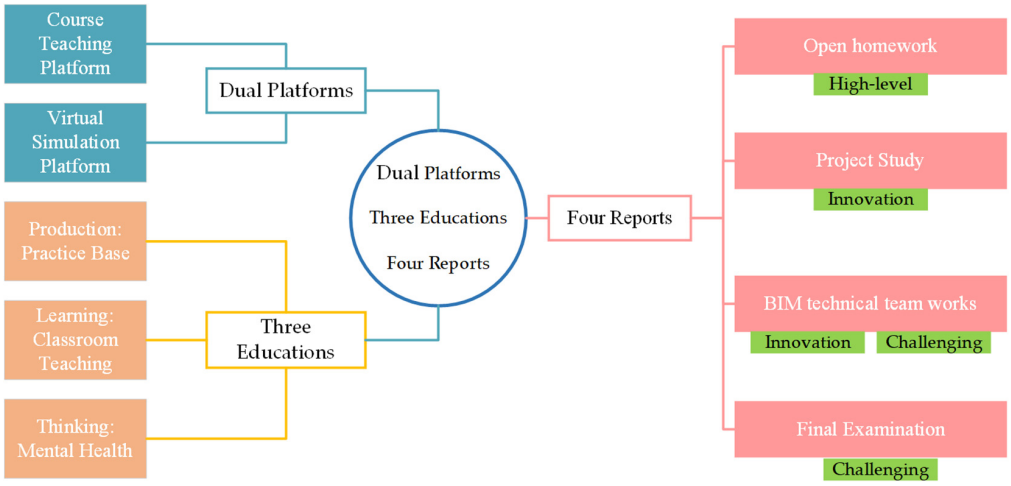

Figure 3. Course innovative thinking.

5.2. Teaching Practice

5.2.1. Dual Platforms

The first teaching platform is the Chaoxing Fanya platform. It is not only a platform for data uploading, but also maximizes the information technology of the teaching website by flexibly using its various functions such as discussion, quick answer, test and PBL in class.

The second teaching platform is the virtual simulation laboratory. Virtual-simulation technology has the advantages of intuitiveness, operability and repeatability, which enables students to conduct safe, economical and repeatable simulation practice in an open, independent and interactive virtual environment. It exemplifies a new way of teaching reform. In 2018, the virtual-simulation center of the university completed preliminary construction, which included the teaching conditions for virtual simulation. The hardware and software facilities for virtual simulation are shown in Figure 4.

(**a**) (**b**)

Figure 4. Hardware and software devices for virtual simulation. (**a**) Construction technology VR; (**b**) safe and civilized construction VR.

5.2.2. Three Educations

The mixed teaching mode of "Three Educations" guided by the OBE concept is adopted, and the "Three Educations" mode combined with on-site production education, classroom-learning education and mental-health education in actual teaching can effectively improve the comprehensive quality of students.

(1) Production-site education. In order to improve students' awareness and understanding of construction production sites, students will go deep into construction sites and have zero-distance contact with engineering, which will effectively stimulate students' interest in learning and cultivate their ability to explore. Table 1 shows the main practical-education foundations of the course and the specific content of the corresponding on-site learning.

Table 1. On-site learning activities of practical production and construction.

No.	Practice Base	On-Site Learning Content
1	Zhejiang Zhongqingda Architectural Industrialization Co., Ltd.	Factory manufacturing process for prefabricated components of prefabricated buildings
2	Zhongsha Construction Group	Hoisting and installation of prefabricated components in prefabricated construction site
3	Huahui Engineering Design Group Co., Ltd.	Deep foundation engineering construction technology
4	Changye Construction Group	Construction technology of concrete engineering in housing construction
5	Tongchuang Engineering Design Co., Ltd.	Road subgrade construction, bridge prefabricated-component lifting
6	Zhejiang Mingye Project Management Co., Ltd.	BIM technology for network planning
7	Huanyu Group	BIM technology for visualization of construction scheme
8	Jinggong Steel Bulding Group	Steel-structure-component factory production technology, steel-structure joint technology
9	Glodon Company Limited	BIM5D construction-management technology

In addition to zero-distance contact with the construction site, the activity of "Industry Elites Entering the Classroom" is also organized; experienced engineers from enterprises are invited to the university to give lectures on cutting-edge engineering technologies such as BIM and prefabrication, so that students can closely integrate learning content with the actual situation of the industry. At the same time, these lectures expand students' vision and thinking, and effectively improve the sustainable development nature of students' employment. Since 2017, we have maintained close cooperation with Zhejiang Zhongqingda Architectural Industrialization Co., Ltd., Huahui Engineering Design Group Co., Ltd., Tongchuang Engineering Design Co., Ltd., Changye Construction Group, Glodon Company Limited and other enterprises, and carried out 32 classroom activities for elites in the industry, and achieved excellent results.

(2) Classroom learning education. On the basis of the traditional classroom teaching mode, a series of innovative learning methods were added. The traditional classroom mode is mainly based on simple PPT explanations, blackboard problem solving and teaching aids' display. To the innovative classrooms have been added rich learning methods such as group puzzle practice, whole-class interactive lectures, and virtual simulations, allowing students to improve classroom-learning enthusiasm, help students to vividly imagine to realize the teaching content, stimulate students' interest in learning, cultivate students' team spirit, and improve students' innovative ability, practical ability and problem-solving ability [10]. In the whole-class interactive lecture, mainly both student–student interaction and teacher–student interaction are adopted. Student–student interaction is dominated by group discussions, group reports and mutual evaluations between groups. It mainly cultivates students' interactive learning and self-solving abilities of difficulties and puzzles, and trains students' active discussion and communication skills. Teacher–student interaction is mainly based

on classroom discussions, classroom guidance and online communication. Through classroom communication, teachers can quickly understand students' learning difficulties, and effectively solve students' problems through detailed guidance. Online communication mainly solves students' learning problems after class. Students put forward questions online, other students can discuss them, and teachers give guidance, which adds a variety of learning paths for students in their spare time, increases the communication between teachers and students, and cultivates strong teacher–student friendship.

Zhang [11] introduced a method like ours to improve students' learning of energy systems through classroom homework, which was applied to a technical elective course called "power generation system" in a course of mechanical engineering. The feedback from students proved that the self-development and use of this tool can significantly improve students' learning experience in the implementation of the curriculum, make the curriculum more dynamic, and give students significant confidence in curriculum learning and sustainable application in the future.

In addition to the above classroom-learning content, the teaching innovation of this course also emphasizes the "three integrations" of learning content pre-class, in-class and after-class. Pre-class, students are encouraged to conduct independent learning, and teachers issue learning tasks and guided-learning tests, so that students can have a preliminary understanding of teaching knowledge and lay a certain foundation for classroom learning. In-class, in-depth exercises are carried out, that is, using the above classroom-teaching methods: virtual simulation, group puzzle practice and whole-class interactive lectures, so as to achieve the vividness and richness of the classroom.

After-class, the engineering expansion is carried out: students' knowledge exploration ability is exercised by assigning open homework and project-based learning, as shown in Figure 5. Moreover, the productive collision between book knowledge and practical theory is realized through the activities of industry elites entering the classroom. Through the "three integrations" of pre-class, in-class and after-class, the effective transformation of students' pre-class independent learning to the after-class externalization of skills is completed.

The innovative mode of this course puts special emphasis on the mental-health education of students. Mental-health education is based on the developmental characteristics of students, the laws of psychological cognitive development, and through the theoretical knowledge and methods of psychology, to cultivate students' good psychological quality to achieve the unity of knowledge, emotion, intention and behavior, so as to have a relatively perfect personality and social integrity, and have good adaptability, positive mental state and good behavior habits [12]. With the development of the times, it has become the consensus of colleges and universities to strengthen the emphasis on students' mental-health education [13,14]. Education in colleges and universities is the last stop for students from the campus to society. Therefore, in the process of education, we should not only teach students professional knowledge, but also pay attention to the sustainable development of students. There are many factors that affect students' mental health in the network environment, so they are more likely to be affected by a variety of values in the process of receiving modern education [15–18]. Teachers play an important role in the mental-health education of college students. Therefore, teachers should fully recognize the importance of the sustainable development of students and ensure that students receive comprehensive guidance and development [19]. In the process of implementing mental health education, teachers should also take students' comprehensive qualities and sustainable development as the basis for evaluation, so as to let students participate more actively in educational activities. Learning enthusiasm is a psychological state, which is powerful motivation to stimulate and maintain learning [20–22]. At the same time, teachers should guide students to develop the ability of self-regulation when educating students, so that students can consciously maintain their psychological health, and correct students who have psychological problems in a timely manner [23].

Open assignments for "Civil Engineering Construction" in the first semester of the 2020-2021 academic year

Class: **Name:** **Student ID:** **Complete time:** **Score (Teacher) :**

Topic: Download or take a related construction picture of a "steel bar project" from the Internet.

(1) Indicate the download URL;

(2) Explore the specific knowledge in the picture;

(3) Explain the key construction technology of this picture, and point out its advantages or disadvantages.

Requirements: Pictures and URLs (1) are printed on A4 paper; Parts (2) and (3) can be handwritten.

Insert photos here.	
URL for photo acquisition:	
Specific knowledge points:	
Picture explanation: **1. Basic explanation** **2. Advantages or disadvantages** **3. Improve proposals**	
Self-rating (full score 100)	
Mutual score (full score 100)	

Figure 5. Students' learning tasks: after-class open homework.

(3) Mental-health education. Based on the above requirements of mental-health education, this course actively pays attention to the mental-health education of students, added a large number of mental-health education elements in classroom teaching, and interspersed multiple mental-health evaluation assessments in the course teaching throughout the semester. At the same time, teachers are required to strengthen and improve their own mental-health knowledge and professional ability, encourage students to solve problems creatively, cultivate students' enthusiasm for active learning, and form a positive psychological state. In the whole process of course teaching, teachers should adhere to the organic integration of mental-health education and course knowledge, so that students are always synchronized with practice. Mental-health education can not only help students develop healthy psychology, but also enable students to have noble morals and correct values [24].

5.2.3. Four Reports

The course teaching focuses on the cultivation and application of students' sustainable innovation ability. To this end, a multi-dimensional evaluation system was constructed, and the comprehensive evaluation is mainly carried out through four reports: an open assignment report, special technical study report, BIM technical work report, and final comprehensive written test report, and the quantification scoring of nodes in the whole process is fully implemented so as to fully practice the teaching mode of "Both-nature and One-extent".

(1) Open assignment report. It accounts for 15%, a total of four times. In view of practical engineering problems, on the basis of mastering basic knowledge, students are required to consult relevant literature and exemplify an in-depth understanding of complex engineering problems and cutting-edge technologies in the industry. There is no standard answer for this assignment, and comprehensive evaluation, student self-evaluation and teacher evaluation are adopted.

(2) Special technical study report. It accounts for 15%, a total of six times. Combining the teaching links of the project department classroom and industry elites entering

the classroom, students are required to expand their knowledge, and innovatively complete the project based on the shortcomings of traditional construction technology and project management. Finally, a class report and defense is conducted, and the results of the project study is comprehensively assessed in the form of students' mutual evaluation and teacher's comments.

(3) BIM technical work report. It accounts for 20%, a total of twice. With the development of BIM in the architecture, engineering and construction (AEC) industry, its influence has gradually increased, and countries around the world have begun to pay attention to BIM education and introduce it into university courses [25,26]. Combined with the course teaching content and production-site learning, BIM design software is used to design and produce BIM works such as a construction-site layout, so as to expand students' knowledge and understanding of civil-engineering construction. After the BIM works are completed, a theme report is produced, and the comprehensive results are assessed by the combination of students' mutual evaluation and teacher's comments.

Li [27] put forward and practiced a seven-stage conceptual framework of problem-oriented and project-based learning in traffic-engineering education, which shows that this method can effectively cultivate students' professional ability and preparation ability. Inspired by the method of Li [27], we improved and expanded the amount of after-school homework.

(4) Final comprehensive written test report. It accounts for 50%. The final exam includes multiple choice questions, fill-in-the-blank questions, short answer questions, calculation questions and case-study questions. This section introduces cross-knowledge of advanced mathematics, mechanics, physics, national industry norms, etc., pays attention to the high-level and challenging degree of test questions, adopts a variety of test questions, and fully checks the students' ability to master knowledge and their sustainable application ability.

Through the four reports evaluation system, the achievement of course objectives has continued to grow in these 12 years, as shown in Figure 6. It can be seen that the four reports evaluation system has achieved remarkable results and has a positive effect on course construction.

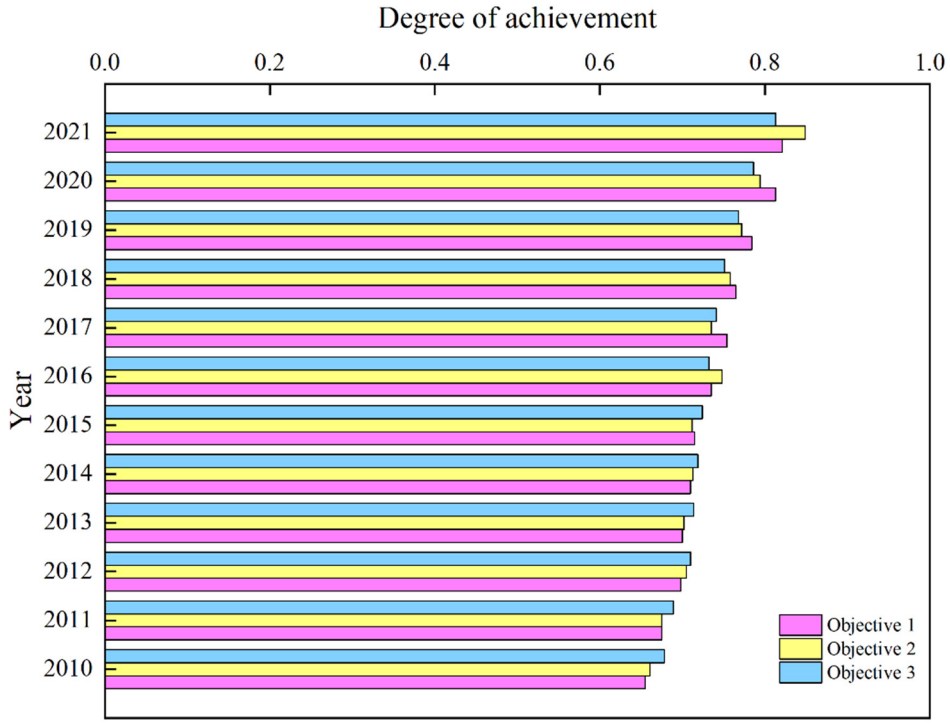

Figure 6. The achievement of course objectives of "Civil Engineering Construction".

The innovation exploration results obtained by the above innovative evaluation methods can be used in later course design, academic thesis and graduation design in the future, and can also be applied to discipline competitions. At the same time, through these methods, an innovative exploration of personalized learning and innovation exploration process can effectively cultivate students' fair-patent thinking and engineering-method thinking, which is of great help to cultivating students' ability to solve complex engineering problems and achieve high-level goals.

6. Innovative Features

The teaching innovation system of "Dual Platforms, Three Educations and Four Reports" has developed the "Dual Platforms" teaching resources of an offline practice platform and online assisted-learning platform. In the teaching process, production and application, classroom teaching and mental-health education are organically integrated to realize the "Three Educations" quality mechanism for the sustainable development of students. Based on being high-level, innovation and challenging, the "Four Reports" evaluation system for the whole process of assessment, including the open assignment report, special technical study report, BIM technical work report, and final comprehensive written test report, was constructed.

School–enterprise co-construction of courses gives full play to the effect of collaborative practice education. With the construction of top-grade enterprises, a course practice base is established combining prefabricated and green-building construction technology, and actively promotes the "project department classroom", so as to cultivate students' engineering-practice thinking. Aiming at cutting-edge industries such as BIM technology and advanced engineering materials, we actively promote the "industry elite entering classroom" to develop students' ability to solve advanced engineering problems.

Thematic open study can cultivate students' engineering innovative thinking. Adhering to the OBE concept, two operation modes are proposed; the open assignment report and special technical study report can provide personalized learning methods. Through group discussion, group report, the student–student interaction of mutual evaluation between groups, as well as the teacher–student interaction of classroom discussion and classroom guidance, the students' innovative thinking in engineering is cultivated.

Through the whole process of mental-health education, we should pay attention to the development of students' mental health. A large number of mental-health education elements were added to classroom teaching, and multiple mental-health assessments are conducted. At the same time, teachers are required to strengthen and improve their own mental-health knowledge and professional ability, encourage students to solve problems creatively, and cultivate students' enthusiasm for active learning, so as to form a positive psychological state.

7. Course Evaluation and Reform Effect

7.1. Evaluation on the Implementation Process of 2P3E4R System

Expert appraisal. Professor M, member of the Civil Engineering Teaching and Steering Committee of the Ministry of Education, and Changjiang Scholar of the Ministry of Education; Professor S, member of the Civil Engineering Teaching and Steering Committee of the Ministry of Education, and Director of the Academic Affairs Office of H University, have given high praise to this course. They both agree that the innovative teaching design of "Dual Platforms, Three Educations and Four Reports" carried out in accordance with the OBE concept well reflects the high-level, innovative and challenging nature of the course, and effectively achieves the goal of course training, which is an excellent offline undergraduate course.

University appraisal. The comprehensive teaching rating of this course in the last semester was Z1, which is the highest level of university appraisal. The university believes that this course is taught in a task-driven way, with good classroom-teaching interaction, focusing on process evaluation and diagnostic improvement, the natural integration of mental-health content, and the effective achievement of course objectives.

Student appraisal. The course is very popular among students. The academic evaluation and teaching score of this course in the most recent semester was 91.61, ranking 9/300. The teaching performance assessment of team teachers for five consecutive years was the highest grade, A. Students think that the pre-learning tasks of this course are vivid and interesting, which can effectively encourage learning. Students can pay attention to the cultivation of mental health while mastering knowledge. The interactive learning in the classroom fully combines theory and practice, laying a solid foundation for future work.

7.2. Evaluation of the of Course Objectives Achievement of Civil Engineering Construction

In order to further analyze and discuss the implementation effect of the 2P3E4R system curriculum scheme, according to the achievement of three curriculum objectives, the students' self-evaluation and employers' evaluation of students were carried out. The survey is divided into four parts, of which the sample number of students was 72 and the sample number of employers was 30. The scoring design of the survey is shown in Table 2.

Table 2. Evaluation achievement grade of curriculum objectives and assignment of degree.

Achievement Grade	Excellent	Good	Pass	Failure
Achievement degree p_i	0.95	0.8	0.7	0.5

Group A: Students' self-evaluation at the end of the course.
Group B: Students' self-evaluation at graduation.
Group C: Evaluation of students by employers after working for one year.
Group D: Employers' evaluation of students after five years of work.

The degree of achievement of course objectives is calculated by the following formula:

$$s = \frac{\sum_{i=1}^{4} p_i n_i}{\sum_{i=1}^{4} n_i} \quad (1)$$

where n_i is the number of people who choose the i-th evaluation level. According to the above calculation, the survey results are shown in Table 3.

Table 3. Survey results of curriculum goal achievement evaluation.

Objectives	Group A	Group B	Group C	Group D
Objective 1	0.80	0.85	0.76	0.85
Objective 2	0.82	0.87	0.80	0.83
Objective3	0.85	0.90	0.70	0.80

Through the above results, we can discuss as follows:

(1) The evaluation results of both students' self-evaluation and employers' evaluation of students are better than the formative evaluation results given by teachers according to the four reports, as shown in Figure 6.
(2) The self-evaluation of students at the end of the course is [0.80, 0.85], indicating that they think they perform well. The study of other professional courses before graduation increases students' self-confidence at graduation, and the self-scoring note increases to [0.85, 0.90].
(3) The lowest evaluation of the employer on the achievement of students' curriculum objectives one year after graduation is [0.70, 0.80], but the corresponding evaluation value increases to [0.80, 0.85] five years later, indicating that students have good sustainable development ability and have been fully recognized by their employers.
(4) Students focus on mastering knowledge during school (corresponding to course objective 1), but employers focus on continuous innovation ability and healthy psychology

(corresponding to course objective 3). These two concerns have the lowest scores in their respective evaluations, but they are still growing. In the future teaching work, teachers should strengthen the cultivation of these two concerns through the 2P3E4R system.

7.3. Achievements and Application of Course 2P3E4R System

Reform effect. After 12 years of teaching accumulation and innovative measures for teaching reform, satisfactory results have been achieved in team building, collaborative education, and teaching effectiveness. In the past 12 years, our students have won 72 awards in BIM-application-skills competitions, intelligent construction and management innovation competitions and other discipline competitions based on this course content. Students, independently, have published 53 papers on construction technology and construction organization, applied for 20 invention patents on prefabricated construction technology, and have won 72 scientific research projects for college students in BIM construction management and other aspects supported by Zhejiang Province or Shaoxing University. Based on the above results, 62 outstanding graduates highly recognized by Shaoxing University and employers have emerged among the students. The specific annual statistical data are listed in Table 4. The team teachers have successively obtained the support of 15 provincial-level teaching-reform projects, including the provincial first-class courses, the provincial virtual-simulation-experiment project, and the provincial college new-form textbook-construction project. At the same time, five teachers have won the provincial five-star young teachers and received individual and other honorary titles.

Table 4. Development of student achievement output in the past 12 years.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Discipline competition award	2	2	2	2	3	4	4	6	10	12	11	14	72
Scientific paper	0	0	1	2	4	5	5	7	6	7	8	8	53
Invention patent	0	0	0	0	1	2	2	3	5	8	10	12	20
Scientific project	1	2	4	4	5	6	6	9	8	8	9	10	72
Outstanding graduates	2	2	2	3	4	4	5	6	6	8	10	10	62

Promotion effect. The teaching innovation mode has been applied to 14 other courses, such as “Construction Engineering Budget”, “Construction Engineering Inspection”, “Engineering Project Management”, and “Operation Research and Engineering Optimization”, as shown in Figure 7. The main information, such as the time when these courses started to use the system, the number of lasting years, the name of their major, course honors, and so on, are listed in Table 5, including three first-class courses of Zhejiang Province and 11 first-class course of Shaoxing University. The teaching evaluation results have improved year by year. The team teachers have participated in teaching conferences and exchanges many times. This teaching innovation mode has been praised by teachers from colleges and universities such as Jiangsu University of Science and Technology, Ningbo Institute of Technology, etc., and has carried out large-scale promotion and application, and achieved excellent results. Practice shows that this teaching innovation mode has certain reference significance for the teaching of engineering courses.

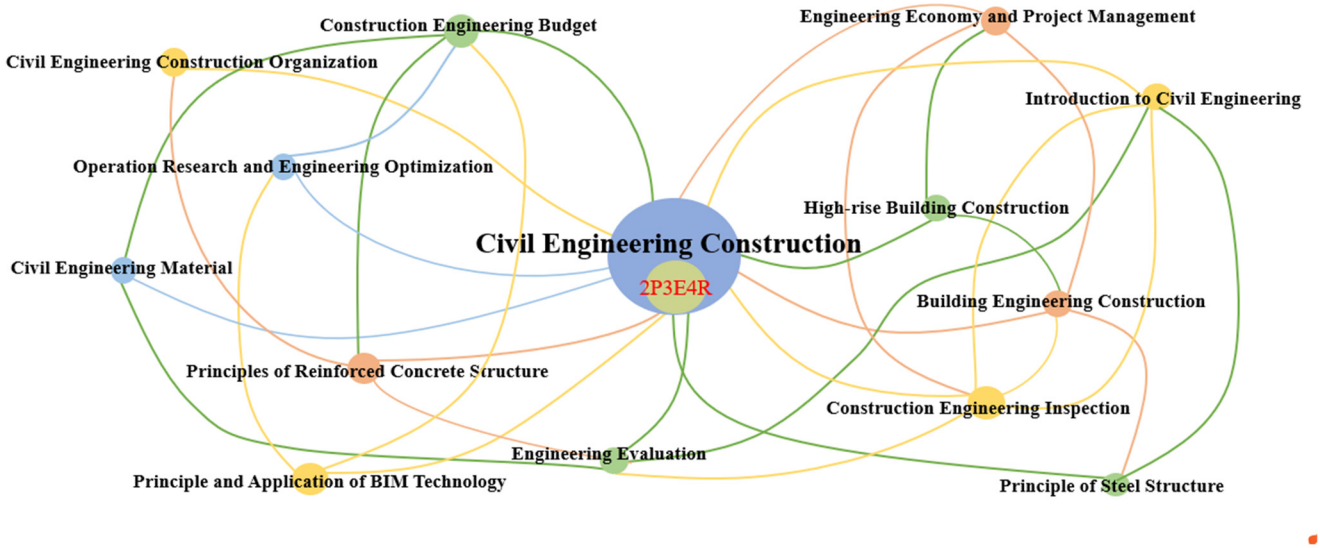

Figure 7. Main courses applying 2P3E4R system.

Table 5. Survey results of curriculum-goal-achievement evaluation.

No.	Course Name	Start Time	Lasting Years	Major Name	Course Honors
1	Civil Engineering Construction	2010	12	Civil Engineering	First-class course, Zhejiang Province
2	High-rise Building Construction	2010	12	Civil Engineering	Key course, Shaoxing University
3	Building Engineering Construction	2010	12	Architecture	Key course, Shaoxing University
4	Civil Engineering Construction Organization	2011	11	Architecture	First-class course, Shaoxing University
5	Engineering Evaluation	2011	11	Architecture	Key course, Shaoxing University
6	Introduction to Civil Engineering	2014	8	Civil Engineering	First-class course, Shaoxing University
7	Civil Engineering Material	2014	8	Civil Engineering	Core course, Shaoxing University
8	Engineering Economy and Project Management	2015	7	Engineering Management	First-class course, Zhejiang Province
9	Construction Engineering Budget	2015	7	Engineering Management	First-class course, Zhejiang Province
10	Construction Engineering Inspection	2015	7	Civil Engineering	Core course, Shaoxing University
11	Operation Research and Engineering Optimization	2016	6	Engineering Management	Key course, Shaoxing University
12	Principles of Reinforced Concrete Structure	2017	5	Civil Engineering	First-class course, Shaoxing University
13	Principle of Steel Structure	2017	5	Civil Engineering	First-class course, Shaoxing University
14	Principle and Application of BIM Technology	2018	4	Engineering Management	First-class course, Shaoxing University

8. Conclusions

This paper presented the construction and practice of the 2P3E4R System for college teaching innovation from the perspective of sustainable development, taking the Civil Engineering Construction course as example.

(1) 2P3E4R System, namely, Dual Platforms, Three Educations and Four Reports, has been gradually established and improved from 2010 to 2021, which enables Civil Engineering Construction course to obtain honor as a key construction course of Shaoxing University and a first-class course of Zhejiang Province.

(2) Focusing on knowledge objectives, ability objectives and emotional-value objectives, this system is of great help to cultivating students' ability to solve complex engineering

problems and achieve high-level goals, enhancing the achievement of course objectives of Civil Engineering Construction from just over 0.6 in 2010 to over 0.8 at 2021.

(3) A survey of thirty employers showed that the achievement of students' curriculum objectives one year after graduation is [0.70, 0.80], but this value increases to [0.80, 0.85] five years later, indicating that students cultivated by the 2P3E4R System have good sustainable-development ability and have been fully recognized by employers.

(4) This teaching innovation mode has helped our college students achieve fruitful and sustainable outputs, including wining 72 awards in discipline competitions, publish 53 scientific papers, apply for 20 invention patents, host 77 scientific projects, and receive 62 outstanding-graduate honors.

(5) This teaching innovation mode has been applied to 14 courses; a good promotion effect has been achieved, including 3 first-class courses of Zhejiang Province and 11 first-class courses of Shaoxing University.

This teaching innovation mode enriches students' learning and thinking methods, and always adheres to the teaching principle of student-centered learning, allowing speculation and exploration to run through the whole teaching process, providing reference for engineering course teaching, and achieving the goal of cultivating new engineering talents based on sustainable development.

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Abbreviations

BIM	Building Information Modeling
OBE	Outcome-Based Education
2P3E4R	Dual Platforms, Three Educations, Four Reports
FD-QM	Fudan University-Quality Matters
AEC	Architecture, Engineering and Construction

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Beyond convenience: practical considerations with using routine health data for evaluations

Routine health information systems (RHIS) comprise data collected at regular intervals at public, private, and community-level health facilities and institutions and health programs. This article looks at how this data may be used for evaluations, and the reasons behind why some are optimistic about this and some have concerns.

S Watson-Grant
MEASURE Evaluation, University of North Carolina at Chapel Hill (UNC), Chapel Hill, NC 27516, USA
Email: watsongr@unc.edu

EG Sutherland
MEASURE Evaluation, University of North Carolina at Chapel Hill (UNC), Chapel Hill, NC, USA

K Xiong
MEASURE Evaluation, University of North Carolina at Chapel Hill (UNC), Chapel Hill, NC, USA

JC Thomas
MEASURE Evaluation, University of North Carolina at Chapel Hill (UNC), Chapel Hill, NC, USA

Corresponding author:
Stephanie Watson-Grant, as above

As digital routine health information systems (RHIS) become more prevalent, there is a growing interest in using them for evaluations. Rakha et al.[1] used data from an integrated management of childhood illness (IMCI) database to evaluate under-5 mortality and the timing of IMCI implementation in 213 districts in Egypt. Bennett et al.[2] used data from Zambia's RHIS to evaluate an insecticide-treated net program and confirmed outpatient malaria incidence. Lalla-Edward et al.[3] used data collected from nine roadside wellness centers in South Africa to evaluate the services accessed by long-distance truck drivers and the drivers' sociodemographic characteristics. Brennan et al.[4] used data from the National Health Service (NHS) in Leicester to assess hospital cost efficiency.

Some researchers are optimistic about this underutilized data source. Wagenaar et al.[5] discussed how certain evaluation designs, such as interrupted time series analysis, are better suited to routine data than to population-based surveys. Others are cautious about routine data's limitations; Ashton et al.[6] expressed 'concerns over internal validity, completeness and potential bias in estimates of program and intervention impact', and Bennett et al.[2] argued that RHIS data cannot be used for rigorous program evaluation without complex modeling strategies.

MEASURE Evaluation used RHIS data to conduct several process and outcome evaluations in low- and middle-income countries (LMIC). From these, we have insights not yet mentioned in the literature on several topics: RHIS data access, quality, and relevance.

National RHIS belong to national governments, to monitor and evaluate health service delivery, health system outcomes, and health outcomes and to improve lives. Ownership and privacy rights are assumed. Often, though, nongovernmental actors are credentialed to build the systems and capture and access data. Furthermore, systems themselves may be housed on servers paid for by nongovernmental partners. Governments have the right to control what is collected, used, and shared[7] and to whom they give access. Patients in some countries, like the United Kingdom, can choose whether their health records are used for evaluation.[8]

National RHIS belong to national governments, to monitor and evaluate health service delivery, health system outcomes, and health outcomes and to improve lives

Depending on the type of data (sensitive, such as HIV status or patient-level records, or important for national security, such as birth and death registrations) and the research purpose, the levels of approval can be numerous, complex, and time-consuming. Yet, these elements of a data system and data sharing should not be perceived as mere procedural hurdles. They reflect the ethical integrity of the system and processes.

A central concern of using routine data for research and evaluations is whether the data can be trusted and whether the data systems and the data stewards are trustworthy. Data quality[9] comprises accuracy, reliability, precision,

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completeness, timeliness, integrity, and confidentiality. The most common metrics – accuracy, completeness, and timeliness – contribute significantly to whether reliable conclusions can be drawn from the data. For mature and well-established routine data systems such as the NHS, patient privacy, data security, and public trust are a preoccupation.[8] The NHS with its large, consistent, and clean data has been called a 'goldmine' for entities interested in voluminous data for pharmaceutical research and machine learning.[10] In addition, concerns have been raised about the use of public assets for commercial and financial gain.[11]

Data quality[9] comprises accuracy, reliability, precision, completeness, timeliness, integrity, and confidentiality

Disease-response definitions, such as confirmed malaria versus suspected malaria, are often conflated in reporting processes. Furthermore, updating and distributing data collection tools such as facility registers can be years behind changes in national policies and indicator definitions. Local contextual changes (e.g. in administrative units) can also affect the data's scope. Finally, updating the data in electronic systems can introduce errors; changes in program outcome estimates affect the ability to determine trends over time.

An evaluation using RHIS data alone should ensure that those data accurately represent indicators of interest. This requires understanding each indicator's definition, how it is disaggregated (e.g. by age and sex), its original data source(s) (e.g. registers), the levels where it is aggregated (e.g. facility and district levels), how it is reported and on which forms (e.g. monthly reporting forms), its frequency of collection and reporting, and how it is represented in the RHIS. Countries with robust RHIS have indicator reference documents, but details are usually incomplete and additional steps are required to map indicator numerators and denominators from their original sources of collection to the RHIS. RHIS data elements are often abbreviated and do not intuitively reflect the names on indicator reference sheets and/or source documents. These discrepancies are rarely documented. Furthermore, many indicators in the RHIS require denominators derived from population-level data sets. Subnational unit or subpopulation estimates are often mathematically modeled from national-level data and come with their own data quality issues. Researchers may not have access to the models used to determine denominators and cannot easily assess how appropriate the models are for the variables used.

Wagenaar, Ashton, and Bennett discuss the methods possible with data generated from RHIS and inherent limitations. However, not until the data are accessed and extracted can the final specification of models take place. Although RHIS data provide repeated measures over time, several factors affect their utility for this purpose: changes in indicator definition, availability of population-based denominators, splitting of administrative units, and levels of disaggregation. Multi-country analyses have similar limitations. For example, indicator elements may be defined or calculated dissimilarly. Finally, when new data sets are created, it introduces provenance management or data origination issues which could become problematic if the software used to manage them are not 'provenance-aware'.[12]

Using data in hand is inevitably cheaper than collecting new data, but cost is not the only consideration. We have described issues of data access, quality, and relevance for methods and questions. The use of routine data to inform population health decisions should continue to be explored and refined. But the current limitations of routine data inherently restrict the questions these data can answer.

ORCID ID
Stephanie Watson-Grant https://orcid.org/0000-0003-1240-5526

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Improved Health Diplomacy is Necessary for Resilience after COVID-19

Daniel B. Oerther, Ph.D., P.E., DEE, M.ASCE

Professor, Dept. of Civil, Architectural, and Environmental Engineering, Missouri Univ. of Science and Technology, Rolla, MO 65401; Director, Engineers Without Borders, 1031 33rd St., Denver, CO 80205 (corresponding author). ORCID: https://orcid.org/0000-0002-6724-3205. Email: Daniel.Oerther@mst.edu

Hester Klopper, Ph.D.

Deputy Vice-Chancellor for Strategy and Internationalisation and Professor, Dept. of Global Health, Stellenbosch Univ., Matieland 7602, South Africa; Past-President, Sigma Theta Tau the International Honor Society of Nursing, 550 West North St., Indianapolis, IN 46202. Email: hklopper@sun.ac.za

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Engineers and nurses share a history of productive collaboration at the bedside designing and deploying technology to monitor individual patients as well as developing systems to support patient health and promote wellness (Zhou et al. 2021). Similarly, engineers and nurses share a history of productive collaboration beyond the bedside—in the public community—promoting health and wellness including access to fresh air, clean drinking water, adequate sanitation, effective hygiene, safe and nutritious food, affordable housing, reliable transportation, and abundant energy supplies (Oerther 2019; Oerther et al. 2019, 2020). As engineers and nurses continue to work together and learn from each other—even while the pandemic known as COVID-19 continues to evolve—we need to explore ways to be more resilient. This includes learning to withstand or recover quickly from difficult conditions while working together to achieve sustainable development, local to global, for individuals (i.e., patients) and the public (i.e., families, populations, communities, nations, and the world). One approach that engineers should adapt from nursing is health diplomacy, including (1) promoting health as a universal human right, (2) coordinating health monitoring and response across national borders, and (3) supporting diverse, equitable, and inclusive approaches to poverty eradication (WHO 2014; Squires et al. 2019; Oerther and Rosa 2020; National Academies of Science, Engineering, and Medicine 2020; National Academy of Medicine 2021).

Lessons from COVID-19

Since the World Health Organization's (WHO's) country office in the People's Republic of China first flagged a media statement describing cases of "viral pneumonia" (December 2019), the number of people infected with SARS-CoV-2 has surpassed 191 million, and the number of deaths surpassed 4.1 million and is still climbing (Adhanom 2020a, b; Dong and Gardner 2020). COVID-19 (SARS-CoV-2) has claimed a place of infamy on the list of the most lethal modern viral pandemics, which includes the 1918 "Spanish flu" (Influenza A virus subtype H1N1), the 1957–1958 "Asian flu" (Influenza A virus subtype H2N2), the 1968–1970 "Hong Kong flu" (Influenza A virus subtype H3N2), and the ongoing AIDS epidemic (HIV).

Not only has COVID-19 contributed to widespread morbidity and mortality, but the consequences of COVID-19 include a reversal of decades of hard-fought gains to eliminate poverty through the United Nations Millennium Development Goals (UN MDGs), and backsliding due to COVID-19 threatens to derail the achievement of the UN Sustainable Development Goals (UN SDGs) by 2030 (Ceschia 2020). In the face of such a significant setback, this article raises the question, "How should healthcare professionals—including engineers and nurses—pick up the pieces and once again move forward to meet the 'grandest challenge of all,' namely achieving sustainability" in the world's low and middle income countries (LMICs) (Mihelcic et al. 2017). To answer this question, two issues come to mind, namely, (1) how will this be done as COVID-19 continues, and (2) how will we ensure a transdisciplinary approach, for example, engineers and nursing working together and learning from each other?

Engineering and Nursing Collaboration

As described previously in a series of editorials in the *Journal of Environmental Engineering*, engineers can learn from and learn with nurses (i.e., Oerther and Watson 2020; Oerther and Shattell 2020; Oerther and McCormack 2021). For example, the importance of governments employing clear, concise, and consistent risk communication is one lesson we (engineers and nurses) can learn from COVID-19 (Oerther and Watson 2020). This fact is highlighted in the unfortunate politicization of the use of face coverings (Oerther and Shattell 2020), as well as in the ongoing debates—pro and con—regarding vaccinations for COVID-19 (Ward et al. 2020).

At least one aspect of the difficulty in addressing risk communication arises from a lack of us (engineers) often failing to consider person-centeredness in typical public health approaches (Oerther and McCormack 2021). While nursing practice often recognizes that individuals (i.e., patients) are autonomous, have an unalienable right to self-determination, and make decisions based in the values each individual holds dear, the public health approaches typically employed by engineering practice often emphasize aggregate measures of people (i.e., the public). Scaling up from the individual and beginning to consider a holistic view of the friends, family, and community of the individual, it is vital that health-care professionals—including engineers and nurses—use appropriate tools to integrate these complex human-to-human relationships.

Health diplomacy, an important component of the emerging concept of science diplomacy, is one tool that engineers should consider as they address human-to-human relationships at the largest public health level of sovereign states—entities possessing a permanent population, defined territory, government, and capacity to enter into relations with other sovereign states (League of Nations 1936). As famously explained by the American journalist Edward R. Murrow (1963), "It has always seemed to me the real art in this business [foreign policy and diplomacy] is not so much moving information or guidance or policy five or ten-thousand miles. That is an electronic problem. The real art is to move it the last three feet in face to face conversation."

Three Dimensions of Science Diplomacy

In 2010, a joint conference of members of the Royal Society in the United Kingdom and the American Association for the Advancement of Science (AAAS) produced a report entitled *New Frontiers in Science Diplomacy* (Royal Society 2010). Science diplomacy was characterized in three dimensions. The first dimension, science-*in*-diplomacy, includes professional diplomats with formal training in science [i.e., engineers serving as diplomats to negotiate international agreements such as the development of the Caribbean Ocean and Aquaculture Sustainability Facility (COAST)] (Oerther 2020). The second dimension, diplomacy-*for*-science, includes multi-national-scale scientific cooperation, such as the WHO, and campaigns promoting cooperation such as the International Year of the Nurse and Midwife: 2020 (WHO 2020). And the third dimension, science-*for*-diplomacy, includes interpersonal-scale scientific cooperation such as study abroad and short-term exchange including the Fulbright program, ERASMUS+, and the Turing Scheme (Oerther and Oerther 2021a).

First Dimension: Science-in-Diplomacy

Recognizing the valuable opportunity for leveraging the scientific, technological, and innovation (STI) leadership of the United States in an increasingly interconnected world, in 2015 the US National Research Council (NRC) published a seminal report entitled *Diplomacy for the 21st Century: Embedding a Culture of Science and Technology Throughout the Department of State* (National Research Council 2015). Glen Daigger—Distinguished Member of ASCE (Dist.M.ASCE), member of the National Academy of Engineering of the US (National Academy of Engineering 2003), and a widely respected environmental engineer—was one of only 15 total members of the NRC committee that produced this report.

The NRC report highlighted the role of the health attaché as s a key contributor to the coordinated global response to health threats. A health attaché is defined as "a diplomat who collects, analyzes, and acts on information concerning health in a foreign country or countries and provides critical links between public health and foreign affairs stakeholders" (Brown et al. 2014). In the US Foreign Service, health attachés were part of the now-defunct ESTH Cone of specialization (i.e., environment, science, technology, and health). Since 1924, the US Foreign Service has recruited some of the best and brightest ... to promote peace, support prosperity, and protect American citizens while advancing the interests of the US in more than 270 posts around the world, and yet between 2004 and 2013, the number of posts (i.e., embassies) with ESTH officers decreased dramatically from 163 to only 50 (Chen 2015). Of particular historical relevance for the current COVID-19 pandemic, the lack of ESTH officers previously was noted as a shortcoming of US health diplomacy during the 2014–2015 Ebola outbreak in West Africa (Chen 2015).

As previously described, environmental engineers may serve as diplomats using STI to advance foreign policy goals (Oerther 2020). For example, the Caribbean nations of Saint Lucia and Grenada purchased an insurance policy developed with the leadership of an environmental engineer serving as a health attaché to US Secretary of State John Kerry. Currently in its third year of operation, the insurance scheme protects small- and medium-scale marine capture fisherfolks from weather-related events, such as high wind speeds creating large waves and excess rainfall creating flooding. By linking food security and livelihoods of fisherfolk with climate-change impacts, including increased intensity and frequency of severe weather, COAST simultaneously advances multiple foreign policy objectives of the United States, including promoting food and nutrition security (i.e., health), protecting marine capture fish stocks (i.e., nature), supporting resilience in the face of a changing climate (i.e., climate), and contributing to the achievements of the UN SDGs (i.e., sustainability) (Oerther 2020).

Second Dimension: Diplomacy-for-Science

Strengthening the leadership of current and future nurses as well as training a net gain of at least 6 million additional nurses have been identified as critical to global health (Dion et al. 2021). Among the health-care professions, nurses make up approximately one-half of the total workforce. And because the majority of nurses are female, advancing the profession of nursing simultaneously supports health at the bedside and in the community as well as promotes financial opportunities among women. Mobilizing the international diplomatic community to prioritize nursing as part of the global response to improving health care is a clear example of the second dimension of diplomacy-for-science. For example, the year 2020 was formally recognized by the World Health Assembly (WHA) as the International Year of the Nurse and Midwife, and to accompany this event the WHO copublished *State of the World's Nursing 2020: Investing in Education, Jobs, and Leadership* (WHO 2020). The success of nurses using diplomacy-for-science to support global health has benefited from a sustained effort on the part of nurses sharing personal relationship around the world, including through the Global Advisory Panel on the Future of Nursing & Midwifery (GAPFON) convened by the honor society of nursing, Sigma Theta Tau International (GAPFON 2017; Klopper and Hill 2015).

Founded in 1922, Sigma is one of the largest nursing organizations in the world with approximately 135,000 active members in more than 90 countries. As a not-for-profit organization with a global mission to "develop nurse leaders anywhere to improve healthcare everywhere," Sigma had the depth of expert health knowledge and breadth of diplomatic relationships to contribute to the mobilization of the global health diplomatic community. GAPFON identified and prioritized five global health issues, including (1) noncommunicable disease, including chronic diseases; (2) mental health, including substance abuse and violence; (3) communicable disease; (4) disaster preparedness and response; and (5) maternal-child health (GAPFON 2017; Klopper et al. 2020). Because Sigma is an international professional organization, it was positioned to attract the attention and support of the global diplomatic community (i.e., WHO), and Sigma leveraged health diplomacy to advance the profession of nursing, support the financial well-being of women and families, and contribute to achieving universal health care throughout the world.

As partners in health, engineers have an opportunity to collaborate with and learn from the leadership demonstrated by nurses (i.e., Oerther 2018a). Similar to the profession of nursing, engineers share personal relationships around the world, including through organizations such as Engineers Without Borders (EWB). Learning from the examples of nurses, environmental engineers should be encouraged to engage with multi-national-scale scientific organizations, such as the UN Environment Programme (UNEP), headquartered in Nairobi, Kenya, which is currently celebrating its 50th anniversary. To pick up the pieces and once again move forward to achieve sustainable development, engineers should leverage our global human-to-human networks.

Third Dimension: Science-for-Diplomacy

Engineers in general, and the civil and environmental engineers who contribute to sustainable development in particular, have and

are continuing to build a global interpersonal network that contributes to the third dimension of science-for-diplomacy. For example, in 2019 Engineers Without Borders-USA (EWB-USA) reported on 707 ongoing projects—partnering with communities to bring clean water, sanitation, improved structures, and more—in nearly 50 countries around the globe (Engineers Without Borders-USA 2019).

Founded in 2002, EWB-USA often is regarded as an example of best practice to engage engineering students and young professionals in service learning (Oerther 2017b). As a not-for-profit organization with a mission to "build a better world through engineering projects that empower communities to meet their basic human needs and equip leaders to solve the world's most pressing challenges," EWB-USA is developing the necessary human-to-human relationships that support the third dimension of science-for-diplomacy. EWB-USA has developed a reputation for resilience in the face of COVID-19, including (1) providing personal protective equipment and water to health clinics in Guatemala, (2) improving access to water in homes in Nicaragua, and (3) promoting handwashing at markets in Uganda (Engineers Without Borders-USA 2020). As engineers help to solve the current COVID-19 pandemic through nonpharmaceutical interventions, including improved indoor air quality and mask wearing (Oerther and Shattell 2020), we also have the opportunity to "build back better"—or to create an improved global health community supporting sustainable development with engineers as valuable contributors. As health-care professionals—including engineers and nurses—move beyond COVID-19 and return to the shared goals of achieving sustainable development, engineers have an opportunity to leverage the interpersonal relationships we have built in efforts such as EWB to attract the attention of the global diplomatic community (i.e., UNEP and others). As we build back better, resilient organizations such as EWB-USA and partners such as ASCE and others need to leverage diplomacy to advance the profession of engineering, end poverty, protect the planet, and ensure health for all people by 2030 (Oerther 2020).

Conclusion

The COVID-19 global pandemic created a significant setback to the world's efforts to achieve sustainable development by 2030. One way that engineers can build back better with an improved approach is to learn from and leverage efforts in health diplomacy as exemplified by the profession of nursing to ensure resilience in individuals, organizations, and systems. As engineers engage in ongoing professional development, and as academic institutions train future engineers, it is important to consider the value of learning how to navigate complex human-to-human relationships, including the three dimensions of science diplomacy (Oerther 2017a). Concrete recommendations for those who are training and educating environmental engineers include (1) adapt theories from nursing to guide engineering best practice, such as Florence Nightingale's Environmental Theory—health is the normal state of humanity, and the purpose of the health-care professional is to modify the environment to restore health and promote wellness (Oerther 2017b); (2) adapt workforce enhancement programs from nursing (i.e., Getting Nurses on Boards campaign) to improve the engineering workforce (i.e., Changing the Conversation campaign) (Oerther 2018a); (3) teach science diplomacy to engineers as part of preconference workshops (Oerther 2021b) and in the classroom and laboratory (Oerther 2017a, 2018b, 2021a); (4) promote joint educational opportunities among engineers and nurses (Oerther et al. 2020); and (5) develop new, convergent educational and best practice models that merge traits of engineers and traits of nurses into new V-shaped professionals (Oerther and Oerther 2021c). Beyond training and education, in our practice, research, and service, engineers must mobilize the global diplomatic community to prioritize engineering as part of the global response to achieving sustainable development—including health as a human right, coordinating monitoring and response, and supporting poverty eradication—through an intentional effort to leverage the success of engineering in science-for-diplomacy (i.e., EWB) to achieve recognition in diplomacy-for-science (i.e., the International Year of the Nurse and Midwife: 2020).

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Enhancing Student Wellbeing Through Social Prescribing: A Rapid Realist Review

Mark Davies[1]*, *Megan Elliott*[1,2], *Sarah Wallace*[3] and *Carolyn Wallace*[1,2]

[1]PRIME Centre Wales, University of South Wales, Pontypridd, United Kingdom, [2]Wales School for Social Prescribing Research (WSSPR), University of South Wales, Pontypridd, United Kingdom, [3]Welsh Institute for Health and Social Care, University of South Wales, Pontypridd, United Kingdom

Objectives: A Rapid Realist Review of social prescribing in Higher Education (HE) was undertaken to determine what works, for whom, how, why, and within what circumstances. The review resulted in the development of a Realist Programme Theory articulating the way in which social prescribing can be implemented within the HE environment.

Methods: Searches of 12 electronic databases were supplemented by citation chaining and grey literature surfaced by the Project Advisory Group. The RAMESES Quality Standards for Realist Review were followed, and the retrieved articles were systematically screened and iteratively analysed to develop Context-Mechanism-Outcome Configurations (CMOCs) and an overarching Realist Programme Theory.

Results: A total of 57 documents were included. The overarching programme theory was developed from the analysis of these documents and comprised of a social prescribing pathway with the following components: (1) An Accessible Gateway, (2) A Skilled Peer, (3) Trusted-Safe-Credible Resources, and (4) A Healthy Setting.

Conclusion: A Realist Programme Theory was developed—this model and associated principles will provide a theoretical basis for the implementation of social prescribing pathways within higher education. Whilst the direct project outputs are of particular significance to the UK HE audience, the underpinning principles can support practice within the global arena.

Keywords: social prescribing, realist review, higher education, student support, wellbeing

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***Correspondence:**
Mark Davies
mark.davies1@southwales.ac.uk

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INTRODUCTION

Within the United Kingdom (UK), it is estimated that up to 20% of Primary Care appointments are for social or economic, rather than medical reasons [1–3]. Mental health issues are now more prevalent within the general population, a situation that has been exacerbated by the COVID-19 pandemic [4, 5]. UK policy and legislative documents have called for new and innovative services to address these challenges [6–8], indicating that resources should deliver holistic support for citizens which promote health and wellbeing.

Social prescribing is a globally evolving initiative [9] which has the potential to address these pressures and prevent future ill health. Models of social prescribing are heterogeneous and highly

complex [10, 11], varying in structure, intensity of service provision, and complexity [12]. Models typically comprise a link worker, also known as a community connector, navigator, or wellbeing advisor, who works with an individual to identify goals and needs and connect them with non-medical community resources [13, 14]. A range of models have emerged over the past decade, varying in structure, complexity, and intensity of provision [15]. Services include informal signposting to community resources and assets, through to holistic support where link workers work closely and co-productively with the individual over a series of appointments to identify resources to meet their needs [12].

Social prescribing interventions have been targeted at a range of population groups and conditions including people who are socially isolated, older individuals experiencing sensory impairment, and those with long term health issues [14, 16–20], but Higher Education (HE) students and young people remain a demographic where further investigation regarding the implementation of social prescribing is warranted. Student wellbeing levels are considerably lower than the general population [21], and marked increases in student wellbeing issues have been observed in recent years [22]. Factors including change of locality, the pressures of independent living and learning, new personal responsibilities all contribute to reduced wellbeing and challenges of adjustment are particularly amplified for mature students, those with declared disability, and learners from Black and Asian Minority Ethnic groups [21, 23–25].

In addition, the student population continue to be considerably affected by the COVID-19 pandemic, impacting on social isolation, stress, anxiety, loneliness, social interactions, and wellbeing [26–28]. Whilst several strategies have been developed [29], effectively supporting student wellbeing remains difficult. Given the struggles experienced by this specific group and the large and increasing number of individuals attending HE [25], the potential for social prescribing within this environment merits further exploration.

This Rapid Realist Review seeks to evaluate social prescribing in HE—informing the development of a service model which will effectively meet the varying needs of a range of individuals. To achieve this aim, five specific review questions were devised:

1. *What* forms of social prescribing interventions are specifically targeted at HE students?
2. *How* do HE students access social prescribing interventions targeting them?
3. *When* do HE students access social prescribing interventions?
4. *For whom* do social prescribing interventions work?
5. *To what extent* does social prescribing work for HE students?

METHODS

Conventional approaches to the evaluation of interventions such as the systematic review focus predominantly upon outcome, i.e., *what works* [30]. In order to understand how a scalable social prescribing pathway may be developed for students in HE, it is imperative to appreciate the impact of context; to understand *how*, *why*, *for whom*, *to what extent*, and *in what context* the intervention works [31]. Realist methodology satisfies these demands; it is a theory-driven approach to the synthesis of evidence, the goal of which is to build a programme theory that explicates what the intervention is, and how it can be expected to work. The Realist Review method is grounded within generative causation, meaning that to infer a causal relationship between an intervention (I) and outcome (O), one must understand the underpinning mechanism (M) connecting them, as well as the context (C) in which they occur. Using the Realist approach, we have unpacked the Context-Mechanism-Outcome configurations (CMOCs) underpinning existing pathways, and in doing so, have built a Realist programme theory of social prescribing for students in HE.

Developing the Project Scope

Refining the focus of the review and developing scope took place collaboratively with an Advisory Group [32] comprising key student services personnel, student representatives, content experts, 3rd Sector partners, and members of the research team from across both institutions. A Population, Intervention, Comparison, Outcome (PICO), and search strategy were developed (**Table 1**), and informal scoping of existing evidence and policy was undertaken to pilot test search terms and build familiarity with existing knowledge relating to social prescribing. Whilst these initial searches indicated that literature focusing specifically upon the use of social prescribing with HE students was limited, examining similar interventions in which social prescribing had been employed, allowed the detection of demi-regularities [33, 34] or causal patterns that formed the basis of CMOCs within this project.

Search Strategy

An Initial Programme Theory (IPT) should be the starting point within any Realist Review—encapsulating views of the research team and Advisory Group regarding how and why an intervention should work [35]. Search terms encompassing the IPT were initially drafted in conjunction with the Advisory Group, executed, and refined iteratively as the IPT was developed. Following further consultation with an information specialist, twelve databases were searched (**Table 1**). Grey literature obtained from Local Authority and 3rd Sector websites from the UK were additionally interrogated, and further documents were provided by the Advisory Group. Citation chaining was also used to identify other relevant documents throughout the review; however given that a Rapid Realist Review was being undertaken [36], there were limited opportunities to add documents to the review in this way. The search results were exported and de-duplicated within EndNote X9 (Clarivate Analytics, Philadelphia PA, USA) before being fully extracted into Microsoft Excel (Microsoft Corporation, Redmond WA, USA) for the research team to have full access. A PRISMA diagram outlining the search is presented within **Figure 1**.

TABLE 1 | PICO & Literature Searches (University of South Wales, United Kingdom. 2022).

PICO framework	
Patient/Population Under Study	HE Students
Intervention	Social Prescribing
Comparison	Students sourcing own wellbeing interventions
Outcome	Impact of specified Social Prescribing model upon overall student wellbeing
Search Terms	
Search Term	Alternate
Wellbeing	Wellbeing, Wellbeing, Wellness,
Resilience	Resilien*, Hardiness, Reserve, Coping,
Isolation	Isolat*, Separat*, Lonel*, Remot*, Living Away, Social Isolation
Relationships	Relationship*, Connection*,
Local Community	Locality, Neighbourhood, Community Group,
Lifestyle	Physical Health, Mental Health, Healthy Living,
Social Prescribing	Social Prescr*, Link Worker*, Link Navigator, Link Coordinator, Community Refer*, Community Connect*, Community Coordinator, Community Navigator, Community Champion, First Contact Practitioner, Local Area Coordinator, Social Capital, Community Asset*,
Student	Student*, Learner*, Part-time Student*, Rural Student*, Liberation Groups, Mature Student*, Students with Declared Disabil*,
Higher Education	HE, FE in HE, University, Tertiary Education
Self-Efficacy	Self-Management
Literature Sources	
Documents	
Primary Care Hub (2018) Social Prescribing in Wales: Final Report. Cardiff: Public Health Wales	
Social Services and Wellbeing (Wales) Act 2014	
Wellbeing of Future Generations (Wales) Act, 2015	
Welsh Government (2018) A Healthier Wales: Our Plan for Health and Social Care. Cardiff: Welsh Government	
Databases	
ASSIA, British Education Index, CINAHL, ERIC, Medline, ProQuest Psychology Journals, PsychInfo, PubMed, Science Direct, Scopus, Social Care Online, Web of Science	
Grey Literature	
Local Authority Websites, Third Sector Websites, University Websites, HE Sector Policy Documents, 'OpenGrey'	
Inclusion & Exclusion Criteria	
Inclusion	Exclusion
English language	Students in FE or Continuing Education
Published literature	
Grey literature	
Students in HE	
Date Range	
All available entries up to April 2020	
Search Strings	
Concept 1 Wellbeing	
Wellbeing OR "Wellbeing" OR "Wellbeing" OR Wellness	
Concept 2 Resilience	
Resilien* OR Hardiness OR Reserve OR Coping	
Concept 3 Isolation	
Isolat* OR Separat* OR Lonel* OR Remot* OR "Living Away" Or "Social Isolation"	
Concept 4 Relationships	
Relationship* OR Connection*	
Concept 5 Local Community	
"Local Community" OR Locality OR Neighbourhood OR "Community Group"	
Concept 6 Lifestyle	
Lifestyle OR "Physical Health" OR "Mental Health" OR "Healthy Living"	
Concept 7 Social Prescribing	
"Social Prescr*" OR "Link Worker*" OR "Link Navigator" OR "Link Coordinator" OR "Link Co-ordinator" OR "Community Refer*" OR "Community Connect*" OR "Community Coordinator" OR "Community Co-ordinator" OR "Community Navigator" OR "Community Champion*" OR "First Contact Practitioner" OR "Local Area Coordinator" OR "Local Area Co-ordinator" OR "Social Capital" OR "Community Asset*"	
Concept 8 Student	
Student* OR Learner* OR "Part-Time Student*" OR "part time student*" OR "Rural Student*" Or "Liberation Groups" OR "Mature Student*" OR "Students with Declared Disabil*"	
Concept 9 Higher Education	
"Higher Education" OR HE OR "FE in HE" OR "Tertiary Education" OR University NOT FE	
Concept 10 Self Efficacy	
"Self Efficacy" OR "Self-Efficacy" OR "Self Management" OR "Self-Management"	
Search Outcomes	

(Continued on following page)

TABLE 1 | (*Continued*) PICO & Literature Searches (University of South Wales, United Kingdom. 2022).

PICO framework	
Total Hits	4,338
Duplicates Removed	2,347
Including Grey Literature from Advisory Group	2,358
For Abstract Screen	349

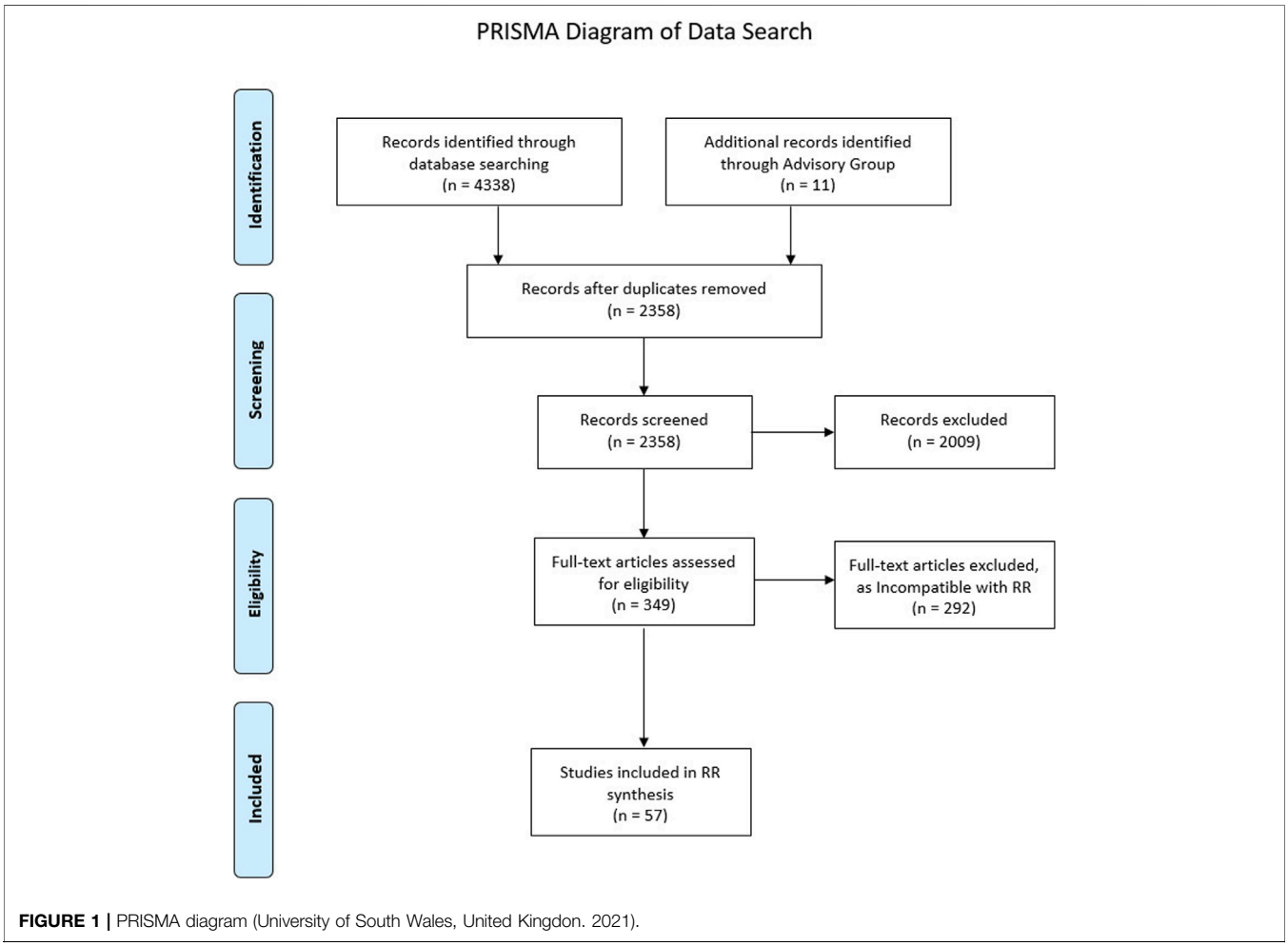

FIGURE 1 | PRISMA diagram (University of South Wales, United Kingdon. 2021).

Selecting Documents

Documents were selected based on the degree to which they addressed the research questions, and ultimately contributed to the development of a Refined Programme Theory. Inclusion decisions were made by the full review team based upon *relevance* - how these data might contribute to theory building, and *rigour*—the degree to which the methods used to generate these data are plausible and trustworthy [34]. Titles retrieved from the searches were initially screened by MD for salience; any deemed irrelevant were excluded at this stage. An abstract screening tool was developed by the project team and utilised to screen the remaining documents and determine if they met the inclusion criteria (**Table 1**). Where it was unclear if the abstracts met the inclusion criteria, the full text document was retained for screening. Abstract screening was undertaken by MD and CW; ME ensured inter-rater reliability by screening 10% of the overall abstracts. Full text screening was completed by MD and CW to establish the final data set for inclusion, and this was transferred to NVivo 12 (QSR International, Warrington, UK) for coding. Again, 10% of the documents were screened by ME, and any disagreements were resolved through engagement and discussion with the project Advisory Group.

Existing evidence was interrogated to further confirm, refine or refute the IPT, leading to the development of an abstracted model explaining how and why our programme works, for whom, to what extent, and in what circumstances [34]. Through an iterative process of data collection, analysis and synthesis [32], CMOCs were built that continued to shape the emerging programme theory. Whilst qualitative appraisal frameworks such as the *CASP Qualitative Studies Checklist* [37] may have significant utility within conventional systematic reviews, they must be applied cautiously in a Realist Review in order to avoid excluding documents which could significantly impact upon programme theory development [32] - even documents that lack methodologically robustness may still potentially contain "nuggets" that could advance the theory building process [38]. Discussing the content of any potentially problematic document within the research team and Advisory Group was helpful in this respect, as was following the *RAMESES Quality Standards for Realist* Synthesis [39] and selecting literature that provided 'conceptually rich' accounts of phenomena [40].

Extracting and Organising the Data

Once the data set was finalised (**Table 2**), full text documents were sourced and located within a shared drive accessible by all team members and transferred to NVivo 12 (QSR International, Warrington, UK) for coding. A data extraction tool using Microsoft MS Excel (Microsoft Corporation, Redmond WA, USA) was also employed to collate information regarding the authors, date, source, nature of intervention, potential CMOCs, overall themes and any reference to substantive theory.

Synthesizing the Evidence and Building the Programme Theory

Full text was first examined by MD who identified initial themes or tentative 'bucket codes' that may reflect a Context, Mechanism, Outcome, or any combination of these. This process continued iteratively as CMOCs were developed, allowing the emerging Programme Theory to be supported, refined, or refuted. CW simultaneously double coded 20% of the data set and both reviewers discussed and agreed the emerging CMOCs. The process was further supported by ME, who was involved in all discussions regarding coding, the development of CMOCs, and the Refined Programme Theory.

The initial bucket codes remained very broad but proved to be a useful stepping-stone as we transitioned from analysis to synthesis. Three key reasoning strategies were employed synergistically to facilitate data analysis, synthesis, and theory building. Careful "observation" of the data resulted in the *inductive* generation of codes, whilst themes or propositions from the initial programme theory/substantive theory were tested against the data in a *deductive* manner to build CMOCs. Finally, *retroductive* reasoning involved using both induction and deduction as well as drawing on one's owns insights in a manner consonant with the abductive reasoning of Peirce [41] in order to elucidate causal mechanisms [42]. A full list of CMOCs can be found within **Table 3**.

RESULTS

Document Characteristics

Overall, 57 documents were included in this Realist Review; none made explicit reference to social prescribing pathways operating within higher education. A range of mental health and wellbeing interventions were however identified; some of these functioned in isolation, whilst others were part of a broader initiative. Documents were from the United Kingdom (n = 18), United States (n = 17), Europe (n = 10), Australia (n = 6), Canada (n = 2), Asia (n = 2), Russia (n = 1) and Iran (n = 1).

Main Findings

The focus of this review was to develop a programme theory explicating how social prescribing might be most optimally introduced to maximise benefit for both those using the services, and the organisations within which the pathways are hosted. Whilst literature relating directly to the use of social prescribing for HE students was limited, several studies articulated processes or pathways that were analogous to elements of the social prescribing process. Examples included using digital systems that linked those with wellbeing or mental health issues with services, mapping assets or resources within the university or wider community, and providing those undertaking a link worker role with effective training and support. Developing CMOCs from the literature also provided opportunities to examine social prescribing pathways created for other groups, e.g., older people living with chronic conditions, identifying demi-regularities [33, 34] that informed the programme theory developed within this project. Analysis of the data surfaced a programme theory in which four specific themes were supported by CMOCs, i.e., *An Accessible Gateway*, *A Skilled Peer*, *Trusted-Safe-Credible Resources*, and a *Healthy Setting.*

An Accessible Gateway

When examining the literature surrounding systems or pathways for those experiencing mental health or wellbeing issues, the issue of routes into support begin to clearly surface as both an issue, and an area for careful consideration. The need for an accessible provision delivered both physically and virtually emerge as a means of reducing stigma associated with services, sharing resources, and (through a process of sharing experiences) developing positive coping strategies [11]. When services are delivered conventionally, students may find accessing these more difficult, particularly if they are not living on campus and only physically attend for limited periods during a week—issues that are further amplified in the current COVID-19 pandemic period. Web-based provision that includes an automated component may be useful in providing support for these groups [43, 44]. The range of provision is not always readily discernible when users are initially attempting to access the pathway, and this can be particularly problematic if services are offered by a range of departments within the university and beyond.

This issue was highlighted in a study examining the inception of social prescribing pathways within Primary Care, indicating that in order to increase engagement for all stakeholders,

TABLE 2 | Final Data Set (University of South Wales, United Kingdom. 2022).

Authors	Date	Article title	Country	Study design	Sample/Setting	Objectives
Abbas, M. A. Eliyana, P. A. Ekowati, D. D. Saud, M. M. Raza, M. A. Wardani, M. R.	2020	Data set on coping strategies in the digital age: The role of psychological wellbeing and social capital among university students in Java Timor, Surabaya, Indonesia	Indonesia	Survey questionnaire	University students	To examine the effects of technology on coping strategies & psychological wellbeing
Agadullina, E. R. Lovakov, A. Kiselnikova, N. V.	2020	Does quitting social networks change feelings of loneliness among freshmen? An experimental study	Russia	Experimental design	Freshman psychology students	To examine the impact of quitting social networks upon loneliness and isolation
Alizadeh, Z. Safaian, A. Mahmoodi, H. Shaghaghi, A.	2018	Pathways between authentic happiness and health promoting lifestyle profiles of the university students in Tabriz, Iran	Iran	Cross-sectional study	Iranian university students	To explore the relationship between and other health promoting behaviours
Altinyelken, H. K.	2018	Promoting the psychosocial wellbeing of international students through mindfulness: A focus on regulating difficult emotions	Netherlands	Qualitative study	International students at a Dutch university	To explore the potential of a mindfulness programme for providing psycho-social support to international students in higher education
Anderson, S. Fast, J. Keating, N. Eales, J. Chivers, S. Barnet, D.	2017	Translating knowledge: Promoting health through intergenerational community arts programming	Canada	Community participatory research project	Older adults and university students	To explore the health and wellbeing benefits of participation in an intergenerational community arts programme
Ashbaugh, K. Koegel, R. Koegel, L.	2017	Increasing social integration for college students with autism spectrum disorder	United States	Experimental design	University students with a confirmed diagnosis of Autistic Spectrum Disorder	To assess whether a structured social planning intervention would increase social integration for college students with Autistic Spectrum Disorder
Bailey, K. M. Frost, K. M. Casagrande, K. Ingersoll, B.	2020	The relationship between social experience and subjective wellbeing in autistic college students: A mixed methods study	United States	Mixed methods study	University students who had identified themselves to the college's disability resource centre	To explore the relationship between the college social experience and subjective wellbeing in autistic student in the Midwestern United States
Barsell, D. J. Everhart, R. S. Miadich, S. A. Trujilo, M. A.	2018	Examining health behaviours, health literacy, and self-efficacy in college students with chronic conditions	United States	Survey questionnaire	Undergraduate students from a Mid Atlantic US university with a self-identified chronic health conditions lasting >3 months	To examine associations between health literacy, self-efficacy, and health behaviours in a sample of college students with chronic conditions
Bertotti, M.Frostick, C. Hutt, P. Sohanpal, R. Carnes, D.	2018	A Realist Evaluation of social prescribing: an exploration into the context and mechanisms underpinning a pathway linking primary care with the voluntary sector	United Kingdom	Realist Evaluation	Users of social prescribing services	To use a Realist approach in order to evaluate a social prescribing pilot in the areas of Hackney and City in London.
Bird, A. Pincavage, A.	2016	A curriculum to foster resident resilience	United States	Case study	Medical students	To evaluate the impact of a 'resilience curriculum' upon resilience and wellness
Boda, Z. Elmer, T. Voros, A. Stadtfeld, C.	2020	Short-term and long-term effects of a social network intervention on friendships among university students	Switzerland	Field experiment & observational study	Undergraduate university students	To investigate the short-term and long-term effects of randomized first contact opportunities on friendship networks in an emerging community of first-year undergraduate students

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TABLE 2 | (*Continued*) Final Data Set (University of South Wales, United Kingdom. 2022).

Authors	Date	Article title	Country	Study design	Sample/Setting	Objectives
Bouteyre, E. Maurel, M. Bernaud, J.	2006	Daily hassles and depressive symptoms among first year psychology students in France: The role of coping and social support	France	Survey questionnaire	First year undergraduate university students	To explore the impact of coping strategies upon daily hassles and depressive symptoms
Brunsting, N. C. Zachry, C. Liu, J. Bryant, R. Fang, X. Wu, S. Luo, Z.	2019	Sources of perceived social support, social-emotional experiences, and psychological wellbeing of international students	United States	Structural equation modelling	Graduate and undergraduate students	To test whether specific social influences could enhance international students' belonging and wellbeing and attenuate loneliness
Budzynski-Seymour, E. Conway, R. Wade, M. Lucas, A. Jones, M. Mann, S. Steele, J.	2020	Physical activity, mental and personal wellbeing, social isolation, and perceptions of academic attainment and employability in university students: The Scottish and British active students' surveys	United Kingdom	Cross sectional surveys	University and college students in Scotland and the United Kingdom	To explore the relationships between physical activity and personal wellbeing within UK university students
Byrom, N.	2018	An evaluation of a peer support intervention for student mental health	United Kingdom	Cohort study	Students within 8 UK universities	To identify students likely to attend peer support and evaluate the acceptability and impact of the intervention
Chandler, G. E. Kalmakis, K. A. Chiodo, L. Helling, J.	2020	The efficacy of a resilience intervention among diverse, at-risk, college athletes: a mixed-methods study	United States	Mixed methods study	US college athletes	To assess the efficacy of a strengths-based resilience intervention upon perceptions of stress, resilience, emotional awareness, and belonging among student-athletes.
Chow, K. M. Tang, W. K. Chan, W. H. Sit, W. H. Choi, K. C. Chan, S.	2018	Resilience and wellbeing of university nursing students in Hong Kong: A cross sectional study	China	Cross sectional descriptive correlation design	Chinese undergraduate nursing students	To explore resilience levels in nursing students and its relationship with wellbeing
Karishma, C. Armstrong, S. Bean, S.	2018	Supporting students facing mental health challenges	United States	Survey questionnaire	Graduate and undergraduate students	To assess anxiety levels in university students and consider potential support strategies
Daddow, A. Cronshaw, D. Daddow, N. Sandy, R.	2019	Hopeful cross-cultural encounters to support student wellbeing and graduate attributes in Higher Education	Australia	Qualitative programme evaluation	University students	To evaluate an extracurricular programme that enabled interfaith and cross-cultural dialogue
Denovan, A. Macaskill, A.	2017	Stress, resilience and leisure coping among university students: Applying the broaden-and-build theory	United Kingdom	Structural equation modelling	University students	To investigate whether resilience predicts leisure coping and positive affect and whether this relationship is predictive of higher levels of wellbeing
Donoghue, J. O'Rourke, M. Hammond, S. Stoyanov, S. O'Tuathaigh, C.	2020	Strategies for enhancing resilience in medical students: a Group Concept Mapping analysis	Ireland	Group Concept Mapping analysis	Undergraduate medical students	To use GCM software to explore and categorise resilience strategies employed by third year undergraduate medical students
Dunn, L. B. Moutier, C.	2008	A conceptual model of medical student wellbeing: Promoting resilience and preventing burnout	International	Literature Review	Undergraduate medical students	To review the literature on medical student stress, coping, and wellbeing in order to develop a model of medical student coping termed the "coping reservoir."

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TABLE 2 | (*Continued*) Final Data Set (University of South Wales, United Kingdom. 2022).

Authors	Date	Article title	Country	Study design	Sample/Setting	Objectives
Enrique, A. Mooney, O. Salamanca-Sanabria, A. Lee, C. T. Farrell, S. Richards, D.	2019	Assessing the efficacy and acceptability of an internet-delivered intervention for resilience among college students: A pilot randomised control trial protocol	Ireland	Randomised control trial (protocol)	University students	To evaluate a newly developed internet-delivered intervention for resilience provided with human or automated support
Galante, J. Dufour, G. Vainre, M. Wagner, A. P. Stochl, J. Croudace, T. J. Benton, A. Howarth, E. Jones, P. B.	2016	Provision of a mindfulness intervention to support university students' wellbeing and resilience to stress: preliminary results of a randomised controlled trial	United Kingdom	Randomised control trial	University students	To assess the efficacy of an 8 week mindfulness course versus usual mental health provision
Gee, K. A. Hawes, V. Cox, N. A.	2019	Blue Notes: Using songwriting to improve student mental health and wellbeing. A pilot randomised controlled trial	United Kingdom	Wait-list randomised control trial	University students with self-identified anxiety	To assess the efficacy of a weekly songwriting programme versus no intervention
Gieck, D. J. Olsen, S.	2007	Holistic wellness as means to developing a lifestyle approach to health behaviour among college students	United States	Cohort study	University students	To examine the influence of a holistic model of wellness on activity level among obese and sedentary college students
Haas, J. Pamulapati, L. G. Koenig, R. A. Keel, V. Ogbonna, K. C. Caldas, L. M,	2020	A call to action: Pharmacy students as leaders in encouraging physical activity as a coping strategy to combat student stress	United States	Commentary paper	Undergraduate pharmacy students	This commentary is a call to action for student pharmacists to take shared ownership over improving the current crisis of student wellbeing - empower their students to guide the improvement of wellness.
Rand Health	2016	Campus Climate Matters: Changing the Mental Health Climate on College Campuses Improves Student Outcomes and Benefits Society.	United States	Research brief	University students	To discuss a CalMHSA prevention & early intervention programme targeting health and wellbeing
HEFCW	2019	HE for a Healthy Nation: Student Wellbeing and Health	United Kingdom (Wales)	Report	University students	Report examining a range of student wellbeing strategies.
Harrer, M. Adam, S. H. Baumeister, H. Cuijpers, P. Karyotaki, E. Auerbech, R. P. Kessler, R. C. Bruffaerts, R. Berking, M. Ebert, D. D.	2019	Internet interventions for mental health in university students: A systematic review and meta-analysis	International	Systematic review and meta-analysis	University students	To search for randomized trials examining psychological interventions for the mental health, well-being, and functioning of university students
Herrero, R. Adriana, M. Giulia, C. Etchemendy, E. Banos, R. Garcia-Palacios, A. Ebert, D. D. Franke, M. Berger, T. Schaub, M. P. Goerlich, D. Jacobi, C. Botella, C.	2019	An Internet based intervention for improving resilience and coping strategies in university students: Study protocol for a randomized controlled trial	International	Randomised control trial (protocol)	University students	To evaluate the efficacy of an unguided internet-based intervention to enhance resilience in university students
Holt, M. Powell, S.	2017	Healthy Universities: a guiding framework for universities to examine the distinctive health needs of its own student population	United Kingdom	Survey questionnaire	University students	To examine the student health behaviours of one university so that future initiatives can be tailored to its own student population

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TABLE 2 | (*Continued*) Final Data Set (University of South Wales, United Kingdom. 2022).

Authors	Date	Article title	Country	Study design	Sample/Setting	Objectives
Husk, K. Blockley, K. Lovell, R. Bethel, A. Lang, I. Byng, R. Garside R.	2019	What approaches to social prescribing work, for whom, and in what circumstances? A Realist Review	United Kingdom	Realist Review	Users of social prescribing services	To develop a programme theory articulating the ways in which social prescribing works, for whom, and in what circumstances
Hussain, R. Guppy, M. Robertson, S. Temple, E.	2013	Physical and mental health perspectives of first year undergraduate rural university students	Australia	Survey questionnaire	Rural university students	To examine the physical and mental health issues for first year Australian rural university students and their perception of access to available health and support services
Kampel, L. Orman, J. O'Dea, B.	2017	E-mental health for psychological distress in university students: A narrative synthesis on current evidence and practice	Australia	Narrative synthesis	University students	To outline the current knowledge and application of e-mental health programs, and to discuss ways that prevention and intervention programs delivered via the Internet and smartphones can be taken to scale to reach a larger number of students to improve their mental health
Knight, A. LaPlaca, V.	2013	Healthy Universities: taking the University of Greenwich Healthy Universities Initiative forward	United Kingdom	Commentary paper	University students	The paper sets out the background to the national Healthy Universities initiative, briefly outlines a pilot initiative; and ends by considering the broader developments in policy and practice
Lattie, E. G. Adkins, E. C. Winquist, N. Stiles-Shields, C. Wafford, E. Graham, A. K.	2019	Digital mental health interventions for depression, anxiety, and enhancement of psychological wellbeing among college students: systematic review	International	Systematic review	University students	To review the literature on digital mental health interventions focused on depression, anxiety, and enhancement of psychological wellbeing among samples of college students to identify the effectiveness, usability, acceptability, uptake, and adoption of such programs
Montagni, I. Cosin, T. Sagara, J. A. Bada-Alonzi, J. Horgan, A.	2020	Mental health-related digital use by university students: a systematic review	International	Systematic review	University students	To summarize and critique studies of mental health-related digital use by students worldwide, to support the implementation of future digital mental health interventions targeting university students.
Murr, A. H. Miller, C. Papadakis, M.	2002	Mentorship through advisory colleges	United States	Case study	Medical students	To outline the development and implementation of an advisory college system that supports medical student wellbeing
Oades, L. G. Robinson, P. Green, S. Spence, G. B.	2011	Towards a positive university	Australia	Commentary paper	University students	The paper explores the concept of the "Positive University."

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TABLE 2 | (*Continued*) Final Data Set (University of South Wales, United Kingdom. 2022).

Authors	Date	Article title	Country	Study design	Sample/Setting	Objectives
Owens, A. R. Loomes, S. L.	2010	Managing and resourcing a program of social integration initiatives for international university students: what are the benefits?	Australia	Mixed methods	International students studying at Australian universities	To report the results of a survey of 446 CQUniversity international students who have had access to enhanced social integration opportunities for integration as well as a focus-group discussion with staff and students
Palma-Gomez, A. Herrero, R. Banos, R. Garcia-Palacios, A. Castaneiras, C. Fernandez, G. L. Llull, D. M. Torres, L. C. Barranco, L. A. Cardenas-Gomez, L. Botella, C.	2020	Efficacy of a self-applied online program to promote resilience and coping skills in university students in four Spanish-speaking countries: study protocol for a randomized controlled trial	International	Randomised control trial (protocol)	University students	To evaluate the efficacy of an unguided internet-based intervention to enhance resilience in university students
Papadatou-Pastou, M. Campbelll-Thomas, L. Barley, E. Haddad, M. LaFarge, C. McKeown, E. Simeonov, L. Tzotzoli, P.	2019	Exploring the feasibility and acceptability of the contents, design, and functionalities of an online intervention promoting mental health, wellbeing, and study skills in Higher Education students	United Kingdom	Cohort study	Graduate and undergraduate students	To evaluate the effectiveness of this intervention protocol in comparison with an active control condition targeting healthy lifestyle, and a waiting list control condition
Primary Care Hub	2018	Social Prescribing in Wales: Final Report	United Kingdom (Wales)	Report	Users of social prescribing services	A report providing an overview of the evolution, efficacy, and implementation challenges of social prescribing in Wales
Randstad	2020	A Degree of Uncertainty: Student Wellbeing in Higher Education	United Kingdom	Survey	University students	To explore the perceptions of students regarding their perceived levels of support whilst studying in UK universities
Ray, E. C. Arpan, L. Oehme, K. Perko, A. Clark, J.	2019	Helping students cope with adversity: a test of the influence of a web-based intervention on students' self-efficacy and intentions to use wellness-related resources	United States	Randomised control trial	Undergraduate university students	To assess the efficacy of an online student wellness intervention versus usual provision
Short, B. Lambeth, L. David, M. Ryall, M. A. Hood, C. Pahalawatta, U. Dawson, A.	2019	An immersive orientation programme to improve medical student integration and wellbeing	United States	Mixed methods	Medical students	To evaluate an immersive orientation programme aimed at promoting student wellbeing through social connectedness
Sibley, S. Sauers, L. Daltrey, R.	2019	Humanity and Resilience Project: The development of a new outreach program for counselling centres at colleges and universities	United States	Case study	University students	To present an overview of a programme developed to increase resilience by encouraging social connection within students at a US university
Stalman, H. M.	2019	Efficacy of the My Coping Plan mobile application in reducing distress: A randomised controlled trial	Australia	Randomised control trial	University students with self-reported elevated levels of distress	To assess the efficacy of an online strengths-focused coping plan app versus usual provision

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TABLE 2 | (*Continued*) Final Data Set (University of South Wales, United Kingdom. 2022).

Authors	Date	Article title	Country	Study design	Sample/Setting	Objectives
Thomas, K. Bendsten, M.	2019	Mental Health Promotion Among University Students Using Text Messaging: Protocol for a Randomized Controlled Trial of a Mobile Phone-Based Intervention	Sweden	Randomised control trial (protocol)	University students	To test the efficacy of a mobile phone–based intervention on positive mental health
Thomas, S. S.	2009	Top 10 Strategies for Bolstering Students' Mental Resilience	United States	Commentary paper	University students	Commentary paper outlining a series of strategies that may be effective in increasing student resilience levels
Thorley, C.	2017	Not by Degrees: Improving Student Mental Health in the UK's Universities	United Kingdom	Report	University students	A report outlining setting forth the challenges surrounding student mental health and wellbeing, and outlining a series of interventions that may be helpful in addressing these
Tierney, S. Wong, G. Roberts, N. Boylan, A. Park, S. Abrams, R. Reeve, J. Williams, V. Mahtani, K. R.	2020	Supporting social prescribing in primary care by linking people to local assets: a Realist Review	United Kingdom	Realist Review	Users of social prescribing services	To understand how such social prescribing connector schemes work, for whom, why and in what circumstances
Wawera, A. S. McCamley, A.	2019	Loneliness among international students in the UK	United Kingdom	Mixed methods	International students at UK universities	To explore loneliness in an international student population in a single university
Webster, N. L. Oyebode, J. R. Jenkins, C. Bicknell, S. Smythe, A.	2020	Using technology to support the emotional and social wellbeing of nurses: A scoping review	United Kingdom	Scoping review	Undergraduate nursing students	To review the literature on the use of technology to offer emotional and social support to nurses
Welsh Government	2018	A Healthier Wales: Our Plan for Health and Social Care	United Kingdom (Wales)	Strategy Document	Population of Wales	The document sets out a long term future vision of a whole system approach to health and social are which is focussed upon health and wellbeing, and on preventing illness
Wiljer, D. Johnson, A. McDiarmid, E. Abi-Jaoude, A. Ferguson, G. Hollenberg, E. Van Heerwaarden, N. Tripp, T. Law, M.	2017	Thought Spot: Co-Creating Mental Health Solutions with Post-Secondary Students	Canada	Case study	University students	To explore the development, utilisation, and impact of a web-based platform that supports students in seeking mental health and wellbeing support

pathways should be integrated with existing systems as far as is reasonably practicable [11].

The range of mental health and wellbeing resources continues to increase [45], but those wishing to use the services may not be aware of the scope of provision, or appropriateness of pathways; a single platform in which these are located may be particularly useful in this respect [44, 46].

A number of documents in the review highlight the stigma associated with formally seeking support [24, 47–51], and this is increased for international students, or those from deprived socio-economic backgrounds [52]. These CMOCs indicate that digital or web-based resources may be particularly useful in ameliorating this issue, empowering students to access support without fear of negative perceptions or judgements.

Discussions around accessibility within the literature focus predominantly upon digital or web-based resources, but CMOCs within this theme also relate to the physical location, highlighting a number of considerations for any physical hubs [49]. Whilst there is a need to mirror digital provision in terms of centralising *information* regarding resources, the data also highlight the role that fellow students can play in raising awareness of wellbeing resources. Although physically locating student wellbeing services in one physical space may be convenient, the literature suggests

TABLE 3 | CMOC List (University of South Wales, United Kingdom. 2022).

Theme	CMOC No (Paper):	CMOC
Accessible Gateway	23	When interventions and/or services are perpetually available online (C), Students feel that there is always support (M), and this increases their sense of safety and overall wellbeing (O)
	49	When students have access to an app that enables them to view a range of alternative wellbeing provision (C), They will engage with healthy coping resources (M) and develop an individual coping plan (O)
	57	When a Social Prescribing pathway is linked to existing IT platforms (C), stakeholders will perceive it as easy to use (M) and engage more readily (O)
	38	When services provide HE students who are vulnerable with useful digital resources (C) they are more likely to engagement with these (O), because they do not feel judged or stigmatised by anyone (M)
	46	When web-based interventions link students into campus resources (C), the students feel less stigmatized (M), and there is greater uptake of Mental Health and Wellbeing services
	29	When resources are made available on-site simultaneously from the university and other partners (C), students feel a greater sense of agency (M) becoming aware of the support available (O)
	29	When student wellbeing champions are present at high traffic student 'hotspots' (C), there is a sharing of resources (M), an increased awareness of the help that is available (O)
Skilled Peer	51	When the student is confident that their needs will be met (M) by a *Gatekeeper's* knowledge of early interventions (C), they will engage with the service (O)
	57	When navigators demonstrate a genuine desire to help by offering personalised support (C), users will believe that they can benefit from the interaction (M) and engage with the service and subsequent Social Prescription (O)
	52	When trusted friends, tutors and parents are involved when students are struggling with wellbeing (C), there is a normalising of stressful experiences (M) and a subsequent building of resilience and improved wellbeing (O)
	57	When establishing the Social Prescribing pathway (C), third sector and community services will buy into the navigator role (O), if they believe that the referrals received are appropriate (M)
	57	When a user perceives the navigator to be part of a formal mental health or social services structures (C), a fear of stigmatising (M) may prevent them engaging with the services (O)
	52	When peer support is provided by student volunteers (C), there is an externalising of MH and wellbeing issues (M), and students deal more effectively with mental health & wellbeing challenges (O)
	16	When student volunteers provide wellbeing peer support (C), they share coping strategies (M), building and maintains positive mood (O)
	27	When students engage in peer-led wellness activities (C), they feel a shared connection and view the activities to be authentic and trustworthy (M), and this increases engagement (O)
	57	Developing systems providing supervision or peer support (C), enables anxieties regarding the role to be shared and explored (M), buffering the psychological pressure the navigator may experience (O)
Trusted-Safe-Credible Resources	38	When credible digital resources are provided (C) students will have confidence and trust in them (M) with consequent high levels of uptake and sustained engagement (O)
	34	When a library of online self-help resources is provided (C), students will believe that self-improvement is possible (M), and their agency and self-efficacy will increase (O)
	56	When students digitally curate community-based wellbeing resources (C), they share their knowledge with peers (M), building support networks and increasing social capital
	07	When students and older community members come together and collaborate on a shared activity (C), social connections are built between the university and wider community (M), and there is increased social capital and associated wellbeing for all parties (O)
	58	When a referral is made to a community asset (C), the service user has opportunities to meet and share experience with those within and beyond the university (M), building their social capital
	57	When developing a Social Prescribing pathway (C), third sector and community services should be active co-producers of the scheme (M), as this enables them to feel like valued partners (O)
A Healthy Setting	36	When organisations adopt a settings-based approach in which university structures, policies, and processed are integrated with wider community health promotion (C), members will feel empowered to make healthy choices within a supportive environment (M), resulting in increased satisfaction & productivity for the whole university community (O)
	28	When organisations create a positive and enabling campus environment where mental health and wellbeing are supported (C), Students feel confident that they will not be stigmatized for accessing support (M) and engage readily with campus services (O)
	32	When organisations using a Healthy University approach (C), identifying the needs of their specific student populations (M), relevant programmes and interventions are developed (O)

that locating peers with knowledge of wellbeing resources within student-centric spaces such as cafés, libraries, or social learning spaces may increase fluency with the services that are available within and potentially beyond the institution [49].

A Skilled Peer

The second theme emerging from this review focuses upon those facilitating the social prescription. The link worker or navigator role is complex, multifaceted, and continually evolving [15, 53],

requiring a wide range of attributes including mental health first aid, safeguarding, advanced interpersonal skills and motivational interviewing, in addition to a comprehensive knowledge of the resources available locally [10, 54]. There is also significant variation in scope, ranging from the "signposting" of services through to a "holistic" model involving significant engagement with clients and intense support throughout the pathway [12]. The CMOCs developed within this theme reflect these challenges—highlighting the knowledge of the navigator, and the importance of trust and confidence in building a supportive relationship between user and link worker [11, 55]. Such attributes are not only integral in building relationships with users of the social prescribing pathway. In order to achieve "Buy In" from those who receive the referral, the navigator must also be viewed as skilled, competent, and capable of generating appropriate referrals to services [11].

When developing a social prescribing pathway within this setting, the value of peer involvement also emerges strongly; the sense of connection and sharing of a common experience translating into the normalising of mental health and wellbeing issues, and development of resilience [52]. The literature also surfaces the potentially stigmatising effect of engagement with conventional mental health services, indicating that a less 'formal' pathway with peer involvement may ameliorate this issue.

Peer input into a social prescribing pathway is viewed as accessible & authentic, facilitating the externalisation of wellbeing issues, and affording a sharing of coping strategies with the pathway user [56, 57].

Whilst the potential efficacy of a peer-led service is supported by the data, the literature also recognises not only the need for effective training, but the potential psychological pressure associated with the navigator role—with processes such as clinical supervision highlighted as important in buffering against these [11]. The review indicates that those undertaking the navigator role must be able to facilitate trusting relationships with those using the services and possess a knowledge of the available interventions. They must also have the ability to select interventions that are appropriate for each user of the pathway; failing to do this effectively will result in a loss of "buy in" and reduced engagement not only from users of the service, but also those providing social prescribing assets within the wider community. The potential psychological burden for those undertaking the navigator role is acknowledged, and buffering systems must be in place. The review data advocates peer involvement within a pathway, but how this may be operationalised is less clear given the issues around training and support.

Trusted-Safe-Credible Resources

The literature and associated CMOCs here illustrate not only the importance of developing a pathway that is accessible and facilitated by an individual with a specific set of attributes, but also the quality of resources and assets that a user may be linked with. A basic web search for wellbeing or mental health resources will generate a significant number of hits, and the nature, scope, and quality of these is particularly challenging for those seeking support [50, 58]. Therefore, a need for resources that have been in some way curated and legitimised emerges from the review. Having access to resources that are perceived as being trustworthy not only increases engagement with services, but also contributes to an individual's sense of agency and self-efficacy [59]. Consonant with findings in earlier themes, peer involvement within this curation process also emerges as being important for both resource sharing and network building—which then contributes to an increase in the social capital of individuals [46]. Other CMOCs supporting this theme relate to co-productive activity involving both users of the service and those providing assets and resources beyond the university. Cultivating these wider support networks increases the social capital of pathway users, embeds the university within the broader community, and acknowledges and values the contributions of partners [11, 60, 61].

This broader relationship between CMOCs may be perceived within this theme. Co-productive working between the university and wider asset/resource providers not only brings those *using* services together, but also fosters closely working relationships between those *delivering* them—developing networks, building social capital, and fostering a common sense of value and ambition. Providing credible resources that are peer-collated and shared, further contributes to this network building whilst increasing agency and overall self-efficacy for those using the pathway.

A Healthy Setting

The final theme emerging from the review focuses upon the macro level institutional climate, articulating how this may impact upon the implementation and ongoing operation of a social prescribing pathway. A number of CMOCs developed echo the "Settings-based Approach" to health promotion outlined within the *Ottawa Charter* [62], and the "Healthy University" movement that emerged from this [63, 64]. The literature recognises that universities are environments in which a wide range of health and wellbeing initiatives are delivered; the "Healthy University" movement recognises this and focuses upon connecting potentially disparate strategies and mapping and connecting a diverse range of stakeholders within and beyond an organisation to address health and wellbeing. It is also worthy of note that the "Healthy University" movement, and the "Whole University Approach" [65, 66] associated with them not only highlight the importance of connected services within the organisation, but also across the wider community in which the university is situated—a finding that is highly congruent with the fundamental ethos of social prescribing [67].

The challenges faced by universities in terms of engaging students with services has emerged repeatedly within this review, particularly the sense of stigma experienced by those who may be accessing services, and the data highlights the enabling impact of a *Healthy Setting* upon this [68]. One must of course recognise that although key universal principles may be inducted from the literature, the profile of the organisation and its constituent community must

also be carefully considered [63]. Thus, this final theme indicates that a social prescribing pathway will function most effectively when situated within a wider organisational culture that is settings-based and actively champions mental health and wellbeing. Services must be co-ordinated (both within the organisation and across the wider community in which the university is situated), and interventions and approaches must be responsive to the needs of the specific student population.

The Refined Programme Theory

The diagram presented within **Figure 2** brings the themes discussed together into a Realist Programme Theory of social prescribing in HE. The student enters the system through an *Accessible Gateway* that may be physical or digital, and it is here that the individual providing the social prescription is initially encountered. The literature is replete with terms to classify both the scope and nature of this complex and multifaceted function [11, 54], but within this review the term "Navigator" is used. This *Skilled Peer* facilitates the social prescription through the "What Matters" conversation and/or signposts the student to a repository of *Trusted-Safe-Credible Resources*. These may include university services, curated information, assets located within the wider community, or a combination of these. Finally, the theory indicates that the social prescribing pathway sits within a wider *Healthy Setting* context that embodies a core ethos of accessibility, inclusivity, support, and empowerment for all members of the university community.

DISCUSSION

We sought to develop a Realist Programme Theory articulating the implementation of a social prescribing pathway within a HE environment. Whilst a range of isolated interventions that may be broadly captured as containing elements of a social prescription surfaced within the literature examined, e.g., an intergenerational arts project involving students and older adults from a local community [60], an online platform that allowed students to crowdsource wellbeing advice [46], we were unable to identify any bespoke pathways for university students. The review therefore represents a novel synthesis and application of the approach. Returning to the Refined Programme Theory (**Figure 2**), key findings may be drawn from the four themes within the review—relating to the pathway entry point, qualities of the social prescription "provider," nature and scope of the resources that are available, and broader institutional context within which the pathway is situated. The key findings may be summarised.

The Gateway

This is the first point of contact with the social prescribing pathway, and accessibility was a fundamental consideration. The review data indicate that there is a very strong preference for online access to wellbeing support which should be available at any time and from any location. As large and complex organisations, universities are comprised of many departments offering a range of services; the review acknowledges this,

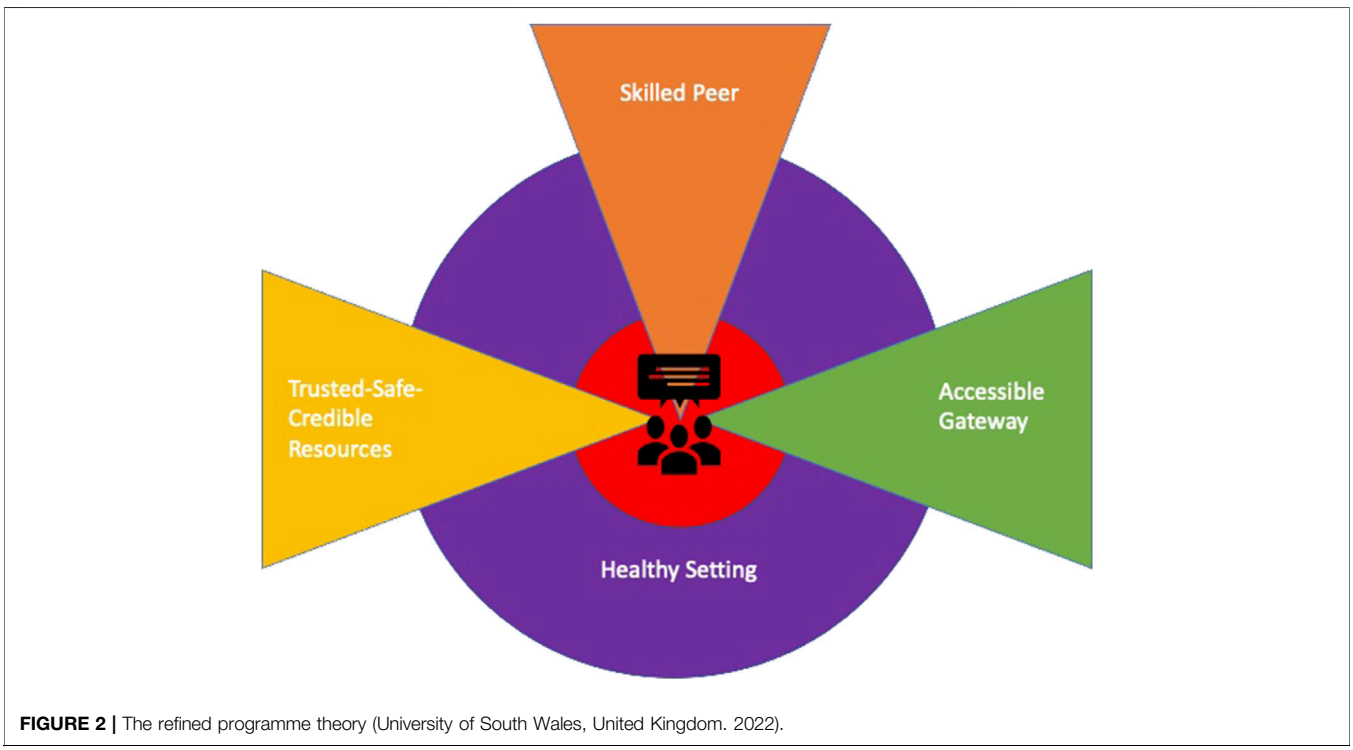

FIGURE 2 | The refined programme theory (University of South Wales, United Kingdom. 2022).

recommending that the social prescribing gateway be linked as seamlessly as possible with existing services—if a bespoke social prescribing IT solution is employed, this should be able to interface with existing systems. For the corresponding physical gateway, attention should be paid to the location. The literature highlights the stigma associated with accessing support for mental health and wellbeing [47, 49–51], and locating a physical hub within a "student owned" space such as a library or café will significantly ameliorate this issue.

The Social Prescriber

The individual instigating a "What Matters" conversation and facilitating the subsequent social prescription is a pivotal component of the pathway. Several of the projects interrogated within the review involved mental health and wellbeing support provided by other students. However, the literature also recognises both the overall complexity and psychological challenges associated with the social prescriber role, and using volunteers in this way would be neither efficacious for the student or nascent social prescriber. Other ways in which peer support can be leveraged may therefore need to be considered when implementing social prescribing pathways, e.g., through peer-led wellness activities [57], or in some form of signposting or advisory capacity [12]. In considering the skills set of the social prescriber, the importance of a knowledgeable individual and well-developed interpersonal skills was evident [61]. However, one must also be cognisant that a social prescribing service requires the nurturing of community assets that exist beyond the university, and if "buy in" is to be achieved from these assets, then the prescriber will also need to cultivate significant Relational Social Capital [69–71], lest the pathway be no more than a signposting system [12] to services within the institution.

The Resources

The third component of the model relates to the trusted and credible resources to which a user of the pathway is referred. The resources made available to the student may consist of services within the university (e.g., finance, counselling, student-run groups), local community assets (e.g., theatre groups, craft groups), digital resources (e.g., apps, online wellness platforms), or any combination of these. Asset mapping is a key process here; the social prescriber identifies potential support systems from within or beyond the university. The online space is also replete with support systems of variable quality, and the review indicates that attempting to discern what may be of genuine value can also be problematic when one is seeking support. For this reason, the review indicates curation of online resources to which those with lower levels of need may be signposted. Providing students with an opportunity to source, curate, and rate both physical and online assets can increase the sense of trust and authenticity for those using the services [46].

The Wider Institutional Setting

The social prescribing pathway here sits within a wider institutional setting. The review data indicates that for a pathway to become more than a "pet" project or series of disparate interventions, the overarching institution must embody a clear commitment to physical and psychological wellbeing, as well as recognising its position as part of the wider community. Adopting such an approach may be challenging for some HEIs, but there is now a ground shift where the importance of a settings-based approach to physical and psychological wellbeing is recognised [63, 67,68].

Revisiting the Review Questions

What Forms of Social Prescribing Interventions are Specifically Targeted at HE Students?

No specific social prescribing pathways directly targeting HE students were surfaced within this Realist Review. Several isolated interventions that contained elements of a social prescription were however identified, and these were drawn upon in terms of developing CMO configurations. The quality of any resources made available to students through social prescribing (*Trusted-Safe-Credible Resources*) features strongly within the review and has become an integral component of the Programme Theory.

How do HE Students Access Social Prescribing Interventions Targeting Them?

The need for an *Accessible Gateway* that spans the physical and virtual environments is pivotal here. Likewise, if one is to effectively gain access to social prescribing and its associated assets, the individual functioning in a social prescriber capacity must be a *Skilled Facilitator* who adopts a holistic approach; cultivating a meaningful relationship through a "what matters" conversation to co-produce a student-centred solution.

When do HE Students Access Social Prescribing Interventions?

The review data indicated that flexibility is paramount; this being particularly well served by the provision of both physical and virtual gateways.

For whom do Social Prescribing Interventions Work?

The interventions that were drawn upon to build the CMOCs and associated Programme Theory spanned a broad range of groups. It is therefore not possible at this stage to discern with any confidence for whom social prescribing interventions work.

To what Extent Does Social Prescribing Work for HE Students?

The extent to which social prescribing works for UK HE students was not discernible from the review data. The Realist Programme Theory here was subsequently tested with participants, and the findings will be reported within a future publication.

Strengths and Limitations

This Rapid Realist Review explores the application of social prescribing within HE. This is a nascent area, and the data indicate the principles of social prescribing may impact positively upon student wellbeing, whilst also facilitating closer working relationships between universities and the wider communities within which they are situated. However, given the limited use of social prescribing approaches within HE, the

range of literature and associated CMOCs was sparse, and there was a requirement to draw significant upon demi-regularities [33, 34] i.e., analogous processes functioning within other student wellbeing interventions. Whilst the direct generalisability of findings is confined to the UK Higher Education environment, it is anticipated that the underpinning principles can support the development of practice within the global arena.

Conclusion

Contemporary literature suggests that supporting student with psychological wellbeing is an ongoing challenge; the review undertaken here indicates that leveraging the principles of social prescribing may be one strategy that could be used to ameliorate this. The review has resulted in the induction of a Realist Programme Theory of *causation* and *implementation*; articulating a pathway that functions specifically within the UK HE content. The underpinning principles may however be useful in the development of cognate approaches at a global scale.

AUTHOR CONTRIBUTIONS

MD prepared the initial protocol, developed the search strategy, facilitated the advisory group, undertook the main searches and document screening at title, abstract and full-text level, carried out the coding and development of CMOCs and refined programme theory and prepared the final manuscript. ME supported development of CMOCs and the refined programme theory, contributed to the interpretation of findings and revised the final report. ME reviewed and commented on the manuscript. SW contributed to the formal search strategies, carried out consistency checks on documents in screening and provided practice expertise and perspective. SW reviewed and commented on the manuscript. CW contributed to the development of the protocol and search strategy, carried out consistency checks on document screening and coding, developed and refined the programme theory and CMOCs and revised the final report. CW reviewed and commented on the manuscript. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that they do not have any conflicts of interest.

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Happy Hookers: findings from an international study exploring the effects of crochet on wellbeing

Pippa Burns
University of Wollongong, pippa@uow.edu.au

Rosemary A. Van Der Meer
University of Wollongong, rvdmeer@uow.edu.au

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Authors:

Dr Pippa Burns (corresponding author)

Lecturer, Graduate Medicine, University of Wollongong

Email: pippa@uow.edu.au

Dr Rosemary Van Der Meer

Honorary Research Fellow, Faculty of Business and Law, University of Wollongong

Email: rvdmeer@uow.edu.au

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Abstract

Aims: With rising rates of mental health disorders reported globally, it is imperative that we investigate economical and accessible ways to increase relaxation and reduce stress. While there is a plethora of anecdotal evidence as to the positive effects of domestic crafts on mental wellbeing, there is little empirical research in this area. As such, we aimed to explore perceived links between crochet and wellbeing.

Methods: An online survey was developed and piloted, based on an existing tool that explored knitting and wellbeing. The final survey was promoted through social media, over a six-week period, resulting in valid responses from 8,391 individuals.

Results: Most respondents were female (99.1%), aged between 41-60 years (49.5%) and living in 87 different countries. Many respondents reported crocheting for between 1-5 years (42.6%). The three most frequent reasons reported for crocheting were to: be creative (82.1%); relax (78.5%) and for a sense of accomplishment (75.2%). Respondents reported that crochet made then feel calmer (89.5%), happier (82%) and more useful (74.7%). There was a significant improvement in reported scores for mood before crocheting (M=4.19, SD=1.07) and mood after crocheting (M=5.78, SD=0.82); z=-69.86, p <.001, r=-0.56. Content analysis of free-text responses identified five major themes: Health benefits; Process of crochet; Personal connection; Crochet as contribution; and Online crochet communities.

Conclusions: The data suggested that crochet offers positive benefits for personal wellbeing with many respondents actively using crochet to manage mental health conditions and life events such as grief, chronic illness and pain. Crochet is a relatively low cost, portable activity that can be easily learnt and seems to convey all of the positive benefits provided by knitting. This research adds to the social prescribing evidence base and suggests that crochet can play a role in promoting positive wellbeing in the general population.

Keywords: crochet, craft, wellbeing, health promotion, social prescribing

Background

Previous research into the impact of arts and crafts as leisure activities has generally come from visual and performing arts and has overlooked the benefits of 'domestic pursuits', such as sewing, knitting and crochet. While there is a plethora of anecdotal evidence as to the positive effects of domestic crafts on mental wellbeing, there has been little empirical research in this area (1–4). Mental wellbeing is defined as "*a state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community*" (5). Depression and anxiety are both ranked within the top ten causes of disability globally, being placed first and sixth respectively and accounting for 10.9% of all years lived with disability in 2015 (6). Globally, more than 300 million people of all ages suffer from depression (7). High rates of mental health disorders are also evident in Australia, with one-in-five Australians aged between 16–85 years reporting having a mental health disorder in the previous 12-months (8). This included 2.3 million (14.4%) with an anxiety disorder and 995,900 (6.2%) with an affective disorder, such as depression (9). While there are effective psychological and pharmacological treatments for both depression and anxiety, there is scope to further investigate non-pharmacological interventions particularly with increasing interest in social prescribing (10). Social prescribing specifically targets those people who are socially isolated and/or living with long-term mental of physical health conditions (11). Primary health care physicians are able to refer patients to a social prescribing coordinator or link worker. This person, in turn, is able to link the patient to existing community groups and organisations. It is postulated that using non-medical interventions to address the broader social determinants of health that are known to affect health allows patients to better manage their conditions (10). It also bridges the gap between health services and the community sector (12).

Crochet

The term crochet is thought to derive from the French word meaning 'hook'(13). Crochet refers to the process of creating fabric by interlocking loops of yarn. Crochet requires a hook and yarn, or thread that will be crocheted. Unlike knitting, where knitters use two needles, crochet use only one hook. With most forms of crochet, usually just one stitch is kept on the hook at a time. Crochet hooks come in a range of sizes and can be made from different materials, most commonly plastic, steel or bamboo. While patterns are widely available, in the English-speaking world, crochet stitches have names that vary by country. These are usually referred to as British (UK) or American (US).

Crochet patterns can also be shared through diagrams. Popular crochet projects include blankets, hats, shawls and bags (14). The first known printed crochet patterns date from the early nineteenth century (13).

Whilst crochet, like many other arts and crafts, declined in popularity during the second half of the twentieth century, the start of the twenty-first century has seen an increase in people, in the United States, undertaking fiber arts including crochet (15). This has been paralleled by the availability of social media platforms that have enabled people to learn crochet and connect with others. Such platforms include, You Tube, launched in 2005 and Ravelry, a free social networking service primarily for people who knit and crochet, launched in 2007 (14). Ravelry allows members to share patterns and finished projects and connect with others locally, nationally and internationally. While crochet is often seen as a domestic activity, it is also rooted in the sciences having been used to create the first durable models of hyperbolic planes, replacing the delicate paper models that were previously used (16). Crochet is also central to the *Crochet Coral Reef* one of the largest science and art projects in the world (17).

There is some, much cited, evidence that knitting helps alleviate depression and reduce anxiety (18,19). Both Riley et al and Corkhill et al investigated the benefits of knitting (n=3545) and found evidence that knitting provided significant psychological and social benefits. Further a Canadian based intervention study introduced knitting to 38 women, with anorexia nervosa who had been admitted to an eating disorder unit (20). The researchers found that nearly three-quarters of participants (74%) reported increased relaxation and comfort and the same proportion reported "benefits of distraction/distancing from their eating disorder thoughts and feelings" (20). Another, US based study, found that knitting and crocheting helped people relax (85%) decreased stress (81%) and decreased anxiety (57%)(21). However, this study did not differentiate between people who knit and crochet. This is an important differentiation as knitting is a bilateral activity (it utilises two needles) whereas crochet is unilateral activity (one hook)(19). Due to this difference, it is argued that those who crochet would also experience the benefits found from knitting. The aim of this research was to investigate the impact of crocheting on individuals' wellbeing and to explore how online craft communities are used to transfer crafting knowledge through social interaction. This paper reports solely on the impact of crocheting on individuals' wellbeing.

Methods

An online survey was compiled to address the aims of the study, using Survey Monkey. The initial survey contained 74 questions. Fifty-four items originated from a survey tool that was used to investigate the impact of knitting on individuals' perceptions of their mental and social wellbeing (18). The wording of these questions was modified to ask about crochet rather than knitting. Survey items included questions related to demographics, mood, cognition and social aspects. The other 20 items related to use of online craft forums, such as Ravelry (https://www.ravelry.com). These questions were adapted from previous studies examining individual motivations and factors the influence online relationships and knowledge sharing in organisational virtual communities (22–24). The results related to the online craft forums are not presented here. Ethics approval was obtained from the university's ethics committee (HREC 2018/067).

To improve reliability and validity, the survey was piloted in a crochet related Facebook group for a period of 24 hours. In this period, nearly three hundred responses were received (n=274). Analysis of the pilot data resulted in a number of changes being made to the survey tool. These changes included the addition of survey logic for some questions and the movement of the demographic questions from the start of the survey to mid-way through, in order to increase completion rates. The final survey contained 71 items.

The final survey was launched at the end of March 2018. The survey was promoted through social media, primarily through Facebook. However, a number of influential crochet bloggers and instagrammers subsequently promoted the survey to their followers. The survey remained live until the end of April 2018. At this point, 8,437 responses had been received during the six-week period that the survey was live. Forty-five surveys were completed by people who did not crochet. These responses were removed leaving a final sample of 8,391.

Descriptive data analysis was undertaken in SurveyMonkey. The data was subsequently downloaded and interrogated through the use of SPSS v.25. The last question was an open-ended question, which asked: "*Is there anything else you would like to add?*". As almost half of respondents left a comment (n=4,028), this data was cleaned and content analysis was undertaken in Microsoft Word (25).

Initially, both researchers reviewed the text for key themes. These were subsequently discussed and refined between the researchers. Where appropriate, individual responses were categorised into multiple themes. Analysis of the free text responses received identified five main themes:

i. Health benefits – responses referring to either mental or physical health benefits gained through crochet were coded under this theme. Mental health benefits included the use

of crochet in dealing with depression, anxiety and stress. It also included the use of crochet through major life events such as death of a close relative, divorce or major illness.

ii. Process of crochet – this theme was used to capture responses that were gained through crochet and included expression of creativity and the rhythmic nature of crochet.

iii. Personal connection – many responses referred to the connections that crochet allows them to form with other people. This theme also included connections made to both past and present generations through crochet.

iv. Crochet as contribution – responses that spoke about crochet making them feel useful or allowing them to contribute to their household or society were coded under this theme.

v. Online crochet communities – this theme included responses referring to online forums and supports around crochet. This included references to Ravelry, You Tube and Facebook. This theme is not directly relevant to wellbeing and is not discussed in this paper.

Responses that had been coded as theme (v.) 'Online crochet communities' were removed from the dataset. Tag Crowd™ was subsequently used to generate a word cloud showing the frequency of words represented by the open-ended responses. In order to optimise this pictorial the following words were excluded: ago, gives, keep, lot, others, really, somethings, things, think, sometimes, and years.

Results

Most people who responded were female (99.1%) and aged between 41-60 years (49.5%) (Table 1). The sample included people living in 87 different countries, with Australia (42.7%) and the USA having the highest representation (21.3%).

Table 1: Age Distribution

Age Group	Female	Male	Other	Total
< 20 years	66	1	2	69 (0.9%)
21 - 30 years	851	5	8	864 (11.2%)
31 - 40 years	1665	14	8	1687 (22.0%)
41 - 50 years	1883	6	1	1890 (24.6%)
51 - 60 year	1902	8	1	1911 (24.9%)
61 - 70 years	1020	8	1	1029 (13.4%)
71 - 80 years	212	2	0	214 (2.8%)
81 years or older	16	0	1	17 (0.2%)
Total	7615	44	22	7615 (100%)

Qualitative Data

Analysis of the free text responses received identified five main themes. Quotes from these themes have been used to support and add context to the quantitative data. The word cloud (Figure 1) reinforces the most popular concepts elicited through the free-text response.

Crochet Habits

For many respondents, crochet was a relatively new pastime with 42.6% reporting crocheting for between 1-5 years (Table 2). Most respondents crocheted at least once a week (90.9%), with over one-third reporting that they crocheted daily (40.1%) (Table 2).

The top three reasons reported for crocheting were: to be creative (82.1%); to relax (78.5%) and for a sense of accomplishment (75.2%).

> *"I find when I am stressed or down, I realise that I haven't done anything creative for a while. As soon as I begin crocheting I find myself relaxing and feeling more grounded again."*
> **Respondent 1346 (Theme: Health & Process)**

"I love to crochet. I live in an isolated community and it has helped me relax and feel a sense of accomplishment that I might not have had otherwise." **Respondent 3713 (Theme: Health & Contribution)**

"I feel a real sense of accomplishment producing something physical with my hands (my job is mostly computer work with no tangible result)." **Respondent 5264 (Theme: Contribution)**

Figure 1: Word cloud showing frequency of responses

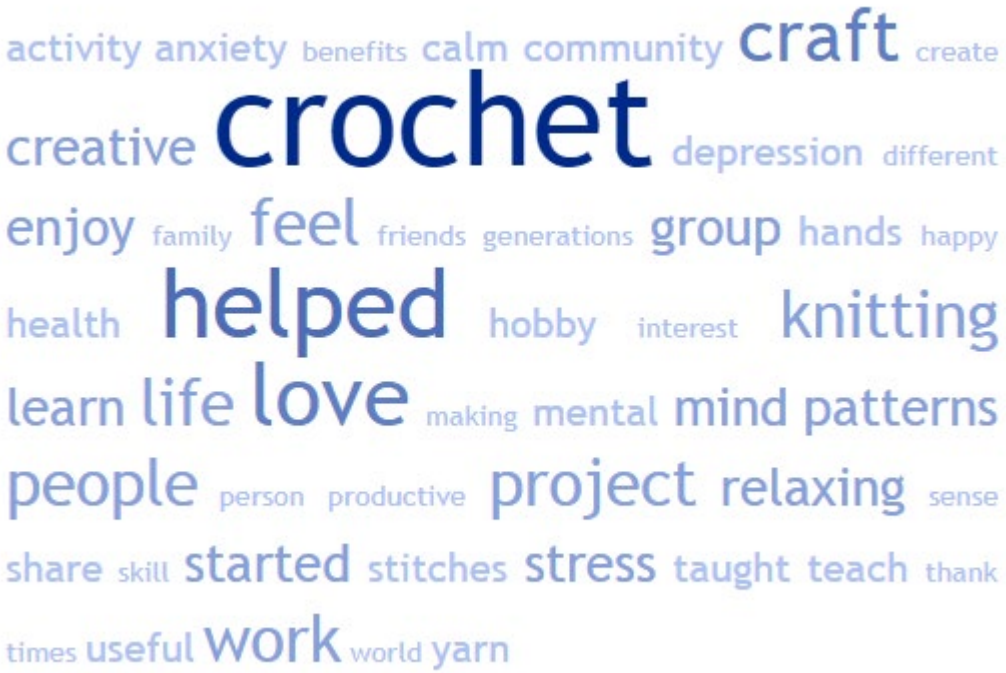

Table 2: How frequently respondents reported crocheting compared to how recently they started crocheting regularly

Frequency of crocheting	Number of years reported crocheting regularly									
	<1 yr	1-3 yrs	3-5 yrs	5-9 yrs	10-20 yrs	20-30 yrs	30-40 yrs	>40 yrs	Total	Frequency of crocheting (%)
Everyday	275	713	622	509	316	180	210	408	3233	40.1%
3-5 times a week	311	770	600	492	285	150	146	265	3019	37.4%
1-2 times a week	101	257	214	164	128	53	71	97	1085	13.4%
Once every two weeks	29	82	63	44	34	16	27	28	323	4.0%
Once a month	27	31	33	27	18	11	19	40	206	2.6%
Less than once a month	46	25	23	29	19	19	22	21	204	2.5%
Total	789	1878	1555	1265	800	429	495	859	8070	100%
Length of time crocheting (%)	9.8%	23.3%	19.3%	15.7%	9.9%	5.3%	6.1%	10.6%	100%	

Respondents were most likely to report crocheting at home (95.8%), whilst waiting for an appointment (50.8%), and at family and friends' houses (46.1%). However, people also reported crocheting in the car (41.1%) and on public transport (25%). The portability of crochet and the way it facilitates social interaction is highlighted through the following quotes.

> *"[…} the number of conversations that have been started by a stranger about the crochet project I'm working on in public never ceases to amaze me!"* **Respondent 1379 (Theme: Connection)**

> *"While you are crocheting, in public like on the train, people like to talk to you, and it is really nice , much better than looking at the phone."* **Respondent 1607 (Theme: Connection)**

> *"It's incredible how many people will come and ask you what you're making, comment on the WIP [work in progress] and the colour/design. It's great!! Who knew! Not me before trying."* **Respondent 2860 (Theme: Connection)**

Crochet process

The texture of the yarn usually or definitely affected the mood of respondents (33.1%), whilst the colour of the yarn had less impact on mood (22.1%). The majority of respondents reported that the finished product was either fairly or very important to them (82.4%). Many respondents imagined others' reactions to their finished projects (42.0%), and just over half of respondents said that they planned their crochet projects in advance (54.2%).

> *"I enjoy the creative process of crochet- choosing colors, textures, patterns."* **Respondent 6887 (Theme: Process)**
>
> "The world turns into a color pallet [sic] and inspiration." **Respondent 4583 (Theme: Process)**

In the final free text question, many respondents chose to talk about the rhythmic nature of crochet.

> *"[…} the rhythmic nature seems to inhibit intrusive thoughts."* **Respondent 45 (Theme: Process)**
>
> *"[…] I find the structure and repetitiveness calming and the creativity exciting."* **Respondent 653 (Theme: Process & Health)**
>
> *"Crochet is, in my opinion, therapeutic. The repetitive counting of stitches and the concentration needed is very relaxing."* **Respondent 2160 (Theme: Process & Health)**

Impact of crochet

Respondents were asked about the impact of crochet on their mood and thinking (Table 3). The majority of people said that crocheting made them feel calm (89.5%) and happier (82.0%). Very few respondents reported that crochet negatively affected their mood by making them feel worthless (0.5%), anxious (0.4%) or sad (0%).

Pearson's chi-square test showed significant association between crocheting at least weekly and feeling: calmer $\chi 2$ (1) = 85.98, p<.001 ; happier $\chi 2$ (1) = 77.47, p<.001; confident $\chi 2$ (1) = 41.87, p<.001; forget pain $\chi 2$ (1) = 43.82, p<.001; useful $\chi 2$ (1) = 12.17, p<.001, and better about yourself $\chi 2$ (1) = 22.87, p<.001. No significant associations were found between crocheting at least weekly and respondents feeling sad, anxious or stressed.

In terms of the impact of crochet on thinking processes respondents felt that crochet was good for their memory (74.2%) and improved their concentration (70.6%). Notably just over half of respondents reported that crochet helped them forget pain (53.8%) and forget problems (51.9%).

Table 3: Impact of crochet on feelings and thinking

Mood	Percentage (%)	Thinking	Percentage (%)
Calm	89.5%	Good for memory	74.2%
Happier	82.0%	Improve concentration	70.6%
Useful	74.7%	Good ideas	58.2%
Better about self	73.4%	Thinking flow	55.1%
Confidence	60.8%	Think more clearly	54.5%
More in control	46.3%	Organise thoughts	54.2%
Excited	36.5%	Forget pain	53.8%
Stressed	2.1%	Forget problems	51.9%
Worthless	0.5%	Think through problems	44.0%
Anxious	0.4%	Dream	20.0%
Sad	0%		

Respondents were asked to rate, on a seven-point scale how they felt both before and after crocheting. A Wilcoxon-signed rank test was conducted to compare reported mood before and after crocheting. There was a significant difference in the scores for mood before (M=4.19, SD=1.07) and mood after (M=5.78, SD=0.82) crochet; z=-69.86, p <.001, r=-0.56, suggesting that crochet positively affects mood.

Respondents also reported actively using crochet to deal with clinical diagnoses such as anxiety and depression and eating disorders.

> *"Crochet has allowed me to decrease my dependency on prescription medications for my anxiety and depression."* **Respondent 982 (Theme: Health)**

"I crochet largely for my anxiety. I have found it has a similar affect on me when I am anxious as playing music, sewing or gardening." **Respondent 1097 (Theme: Health)**

"I learnt to crochet during group therapy while an inpatient at an eating disorder clinic, it helped fill the awkward silences and made me feel like no one was watching me." **Respondent 1451 (Theme: Health)**

Many respondents reported using crochet as a form of therapy, particularly as a means of surviving life-events such as marriage breakdowns, the death of a loved one and illness.

"Just that for me; crocheting has been like medication for me; as I stayed beside my dad's bed as he was dying! When he left; the grief I felt; so painful; eased a bit as I crocheted!" **Respondent 3587 (Theme: Health)**

"[…} since my divorce 3 years ago, I crochet every day. It is my therapy." **Respondent 2729 (Theme: Health)**

"I leant how to crochet because I have a child with an chronic medical condition. I spend so much time in hospital, at appointments and in emergency situations. It's so calming to be productive when you are so useless otherwise. It helps me to not resent the time we spend dealing with illness if I can combine it with a hobby." **Respondent 2596 (Theme: Health)**

Respondents also spoke about the positive impact that crochet had on other aspects of their health, such as decreasing smoking, drinking and blood pressure and dealing with chronic pain.

"Crochet helped me quit smoking and is now helping me cut back on alcohol." **Respondent 21 (Theme: Health)**

"I took it [crochet] up again after Cyclone Debbie. And drinking to[o] much. Haven't given drink away but gone from 2 bottles to 2 glasses daily […]." **Respondent 2861 (Theme: Health)**

"When I have to go to the doctor I always take something to crochet. It has been known to lower my blood pressure before I have to see him. This is a big plus for me." **Respondent 79 (Theme: Health)**

"The repetitive process and motion, the concentration and focus, the sense of accomplishment and the challenge all come together to aid in pain management. It's not something I read about, but something I discovered by doing it. I have a long history of a bad

back and am unable to take pain medicine. The act of crocheting gives me something to focus on besides the pain." **Respondent 697 (Theme: Health & Process & Contribution)**

"Crocheting has made dealing with chronic illnesses less stressful, and keeps my mind off of my multiple symptoms and side effects" **Respondent 2249 (Theme: Health)**

Many respondents commented on how crochet made them feel that they were productive and contributing to their families and/or society.

"[…} I am able to be creative; help others around me through charity work; give people handmade, bespoke gifts; work with gorgeous colours and textures; feel like I'm contributing; and I feel productive." **Respondent 2810 (Theme: Process & Contribution)**

"Crocheting is like meditation but it's also helps me to feel like I'm contributing to my household whilst not able to work due an ankle disability." **Respondent 3502 (Theme: Health & Contribution)**

"[…] It also enabled me to feel productive and capable, kept my brain stimulated and gave me something to show that I had created, as a lot of my work had nothing to show for it!" **Respondent 1014 (Theme: Contribution)**

Crocheting with others

Half of all respondents said that they found it easier to talk to other people who crocheted (50%), which had resulted in over a third of respondents making new friends through crochet (39.2%) and feeling less lonely (31.3%). Despite these reported benefits, only just over a quarter of respondents said that they crocheted with other people (26.3%).

Pearson's chi-square test showed significant association between crocheting in a group and feeling: happier $\chi 2$ (1) = 12.65, p<.001; confident $\chi 2$ (1) = 12.46, p<.001; useful $\chi 2$ (1) = 15.41, p<.001, and better about yourself $\chi 2$ (1) = 12.58, p<.001. No significant associations were found between crocheting in a group and respondents feeling sad, anxious stressed or calmer.

The rest of the answers in this section refer only to this sub-sample of people who reported crocheting in a group setting (n=2,041). Over three-quarters reported that they enjoyed being with others whilst they crocheted (76.7%) and that it gave them a sense of belonging (77.8%). A majority also reported that crocheting with others gave them confidence (69.1%). Unsurprisingly for this group, few reported that crocheting with others made them nervous (0.9%; n=19).

Responses to the open-ended question indicated that the connection that crochet provides to other generations, both past and future was important to many people.

> *"[…] I come from a long line of women crocheters - great grandmother, Aboriginal grandmother, and mother.... and me! It unites us even though all of them have died. and I reflect back on items they made... I have a ball of blue silk yarn that was my great grandmothers... and occasionally I will chain a little of it to feel it run through my hand... I use her hand me down hook as well... I have a collection of hooks from them all. […]"* **Respondent 124 (Theme: Connection)**

> *"[…] It's nice to do something my gran did (she taught me). Sort of like carrying on a tradition by making heirlooms for my kids, using a technique taught to me by their great grandmother. Nice feels :)"* **Respondent 1576 (Theme: Connection)**

> *"Crocheting is a skill I do so I can pass it down through the generations and to make beautiful quality things to treasure and become heirlooms."* **Respondent 2369 (Theme: Connection & Contribution)**

Discussion

The online survey received a large response rate (n=8,391) which is reflective of the recent resurgence in popularity of crochet, interest in the connection between crochet and wellbeing and social media attention (26–29). As far as we are aware this is the first study of its kind to attempt to quantify the effects of crochet on wellbeing, although positive case-studies exploring this association exist (30).

The majority of respondents were female (99.0%) which is similar to respondents of the survey exploring knitting and wellbeing (98.8%) (18). It is also reflective of the fact that craft is often seen as a domestic craft, and as such, women's work (31). The modal age of respondents was 51-60 years, which was considerably higher than respondents in the knitting survey (21-30 years) (18). Some of this variation is likely due to older adults becoming more familiar with technology in the intervening eight-year period, as both surveys were administered online. However, crochet and other domestic crafts are still often viewed as something undertaken by women of previous generations out of necessity. The results strongly suggest that for many people crochet provides a non-pharmacological

adjunct to psycho-social wellbeing. Further, crochet is a relatively cheap and portable craft that is easily learnt and can be readily adapted to suit individuals' needs and skill level. This is important as we know that the risk of becoming depressed is increased by poverty, which is mediated by life events such as unemployment, grief and loss, physical illness and drug and alcohol use (6)

Crochet process

Most people reported crocheting at home (95.8%) which was similar to respondents of the knitting study (98%) (18). The impact of colour and texture was less for people who crochet (22.1% and 33.1%) than knitters (24.0%; and 46.0%) (18). It is not clear why this difference has occurred, however, it should be noted that we did not explore the impact of the yarn content e.g. acrylic verses natural fibres on mood.

Crochet habits

Respondents reported crocheting for the following benefits creativity (82.1%); relaxation (78.5%) and accomplishment (75.2%). These reasons were also reported in a 2014 survey of people who knit and crochet, but at somewhat different rates: creativity 65%, relaxation 90% and sense of accomplishment 44% (21). It is likely that the different proportions reflect the way in which the questions were framed in each survey.

Impact of crochet

Respondents reported that crochet made them feel calmer, happier and more useful. Respondents also reported that crochet was good for their memory and that it helped improve their concentration. These results support research that has shown that older adults, aged 70-89 years, have decreased odds of developing mild cognitive impairment, when they reported participating in craft activities, such as knitting, (32).

The qualitative comments provided examples of respondents using crochet to help manage pain and deal with eating disorders. Such effects have also been reported with knitting (20,33).

Comments from many respondents indicated that the benefits that they gained were from the rhythmic and repetitive nature of crochet. They also spoke about the meditative properties of

crochet. It is likely that these comments are due to crochet eliciting the "relaxation-response". The relaxation-response has been identified as a way of counter-acting the flight or fight response. To elicit the relaxation-response, it is suggested that the technique, described below, be carried out for between 10-20 minutes each day.

> *"Find a quiet, peaceful environment for practice; muscles should be consciously relaxed; a word such as "one" or "peace," or a phrase, possibly a prayer, should be repeated silently in the mind; any intrusive thoughts should be observed only and then passively dismissed; and breathing should be slow and deep"* (34).

The parallels between this practice and crochet are apparent, where the phrase being repeated is often the stitch count. A review of the literature suggested that the relaxation-response was effective in reducing hypertension, insomnia, anxiety, pain and medication use across population and settings (35), which further supports the findings of this study.

Crocheting with others

Far less respondents said that they crocheted in a group (26.3%) than compared to respondents in the knitting survey (50.3%) (18). It is unclear why this is the case, and such reasons could be explored in the future through qualitative interviews or focus groups. However, respondents reported being less lonely through crochet (31.3%) and over one-third reported having made new friends through crochet (39.2%), which is similar to the proportion reported in the knitting study (18). This suggest that participating in crochet has a positive impact on social connectedness, supporting its use in social prescribing.

The sense of connectedness to both past and future generations was an unexpected finding and was not reported in the knitting study.

Ideally, future research will include a multi-grouped randomised control trial comparing crochet amongst experienced and inexperienced people (as we know that learning to crochet is hard and a potential stressor (1)), and a control group. Such a design would allow the effects of crochet on wellbeing to be measured, whilst controlling for experience. There is also scope to conduct similar, survey-based research, investigating the impact of other crafts such as spinning, quilting, embroidery, tatting and weaving on wellbeing. Such research would add evidence to the options promoted through social prescribing.

Strengths & Limitations

One of the strengths of this survey is that we used the same tool previously used to examine wellbeing in people who knit (18), allowing direct comparison of the results. Secondly, a large international sample of people who crochet was obtained, suggesting validity. A number of international events may have affected the overall response to the survey. Primarily, the number of total respondents is likely to have been compromised by the Cambridge Analytica data scandal, which broke in March 2018. This scandal involved the release of user data from more than 87 million Facebook users to a third party company (36). A number of comments left in Facebook groups in which this survey was promoted suggest concern, even anger, that data harvesting was occurring, despite the fact that the survey link went to Survey Monkey and contact details for the University's Ethics Committee were supplied. This raises questions around general online literacy. Conversely, it is likely that April 2018 being National Stress Awareness Month positively affected the number of responses received and interest in the research.

Like much survey research, this project utilised a convenience sample, therefore those most interested in crochet were more likely to take part, potentially influencing the generalisability of the results. We also did not distinguish between people who solely crochet and those who both crochet and knit. Like all surveys, respondents were required to answer questions that may have led to social desirability bias. Further, the survey tool was only available in English, preventing people who did not read English from taking part.

There were a number of areas in which the survey did not elicit sufficient detail, this includes the fact that there are many different forms of crochet e.g. thread crochet (lace crochet), free-form crochet and Tunisian crochet and it is possible that the different forms of crochet have a different impact. Further, we did not tease out differences in impact between creators (those following a pre-existing pattern) and designers (those creating the patterns). Finally, many people reported being crocheting sporadically. This seemed to be influenced by the time of the year, with many respondents reporting crocheting in winter. This variability needs to be investigated further through qualitative research, which would allow in-depth exploration of the issue, in order to ensure that future interventions are successful.

Conclusions

We have shown for the first time that many people believe that crochet provides positive benefits for their personal wellbeing. Crochet is a relatively low cost, portable activity that is easily learnt and seems to convey all of the positive benefits provided by knitting. This study highlights the need for increased multi-disciplinary research across arts, medicine and health, and in particular the need to explore the impact of crafts that were previously seen as domestic work.

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Ethics approval and consent to participate

The survey protocol was approved by the University of Wollongong and the Illawarra Shoalhaven Local Health District (ISLHD) Human Research Ethics Committee (HREC 2018/067). The survey was anonymous and participants were informed of the study aims at the start.

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Competing interests

The authors declare that they have no competing interests.

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RESEARCH

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Inequalities in the burden of non-communicable diseases across European countries: a systematic analysis of the Global Burden of Disease 2019 study

Carlos Alexandre Soares Andrade[1], Nour Mahrouseh[1], Jonila Gabrani[2], Periklis Charalampous[3], Sarah Cuschieri[4], Diana Alecsandra Grad[5,6], Brigid Unim[7], Enkeleint A. Mechili[8,9], José Chen-Xu[10,11], Brecht Devleesschauwer[12,13], Gaetano Isola[14], Elena von der Lippe[15], Carl Michael Baravelli[16], Florian Fischer[17], Nanna Weye[16,18], Mirza Balaj[19], Romana Haneef[20], Mary Economou[21], Juanita A. Haagsma[3] and Orsolya Varga[1*]

Abstract

Background Although overall health status in the last decades improved, health inequalities due to non-communicable diseases (NCDs) persist between and within European countries. There is a lack of studies giving insights into health inequalities related to NCDs in the European Economic Area (EEA) countries. Therefore, the aim of the present study was to quantify health inequalities in age-standardized disability adjusted life years (DALY) rates for NCDs overall and 12 specific NCDs across 30 EEA countries between 1990 and 2019. Also, this study aimed to determine trends in health inequalities and to identify those NCDs where the inequalities were the highest.

Methods DALY rate ratios were calculated to determine and compare inequalities between the 30 EEA countries, by sex, and across time. Annual rate of change was used to determine the differences in DALY rate between 1990 and 2019 for males and females. The Gini Coefficient (GC) was used to measure the DALY rate inequalities across countries, and the Slope Index of Inequality (SII) to estimate the average absolute difference in DALY rate across countries.

Results Between 1990 and 2019, there was an overall declining trend in DALY rate, with larger declines among females compared to males. Among EEA countries, in 2019 the highest NCD DALY rate for both sexes were observed for Bulgaria. For the whole period, the highest DALY rate ratios were identified for digestive diseases, diabetes and kidney diseases, substance use disorders, cardiovascular diseases (CVD), and chronic respiratory diseases – representing the highest inequality between countries. In 2019, the highest DALY rate ratio was found between Bulgaria and Iceland for males. GC and SII indicated that the highest inequalities were due to CVD for most of the study period – however, overall levels of inequality were low.

Conclusions The inequality in level 1 NCDs DALYs rate is relatively low among all the countries. CVDs, digestive diseases, diabetes and kidney diseases, substance use disorders, and chronic respiratory diseases are the NCDs

*Correspondence:
Orsolya Varga
varga.orsolya@med.unideb.hu
Full list of author information is available at the end of the article

that exhibit higher levels of inequality across countries in the EEA. This might be mitigated by applying tailored preventive measures and enabling healthcare access.

Keywords Health inequality, European Union, European Economic Area, Non-communicable diseases, DALY rate, Global Burden of Disease

Background

Non-communicable diseases (NCDs) comprise many chronic diseases such as cardiovascular diseases (CVDs), cancers, diabetes mellitus (DM), and respiratory diseases. The global number of deaths attributable to NCDs is 41 million people per year, which represents 74% of all deaths in 2019 [1, 2]. Despite higher mortality and fatality in the older age group, 42% of NCD-related mortality occurs in people under 70 years old [1, 2]. Most NCDs are linked to four specific health behavioral risk factors: smoking, harmful alcohol consumption, unhealthy diet, and physical inactivity which result in four specific metabolic-physiological abnormalities: elevated blood pressure, overweight/obesity, elevated blood sugar and elevated cholesterol [3, 4].

Beyond these behavioral risk factors and medical conditions, the prevalence of NCDs is associated with low-socioeconomic position (SEP) [5]. Several risk factors of NCDs, such as smoking and physical inactivity, are also related to SEP [6]. The correlation between NCDs' prevalence and SEP also holds at the population level, where occurrence of CVDs, such as stroke and coronary heart disease, are strongly associated with lower GDP per capita and health expenditure per capita [7]. In the past decade, the prevalence of type 2 DM has increased, partly because of the population's poor working conditions, low income and educational level [6]. However, the prevalence rate of type 2 DM in high-income countries is higher compared to low- and middle-income countries [8].

Despite improvements in the overall level of health in many European countries, there are significant inequalities in health due to NCDs [9]. The inequalities in NCD prevalence rates within European have a social gradient and socioeconomic gaps, with lower classes experiencing higher NCD rates for most diseases [10]. Reducing these disparities has long been recognized as a major public health challenge [11].

Health inequalities refer to unjust and avoidable differences in people's health status, both within and between population groups [12]. The impact of health inequalities on society is well illustrated by the magnitude of the economic costs of socioeconomic inequalities in health. A study in 2011 showed that inequalities in health cause more than 700,000 deaths and 33 million cases of illness across the entire EU, annually [13]. They are responsible for 20% of the total healthcare expenditure and 15% of social security expenditure [13]. Inequality-related health losses diminish labor productivity and cut GDP by 1.4% a year, and the monetary value of inequality-related welfare losses is estimated by the study at €980 billion a year, or 9.4% of GDP in the EU [13].

Health inequalities in Europe have been a subject of extensive research, mostly focused on prevalence and mortality inequalities between eastern, western, and central regions [14–17]. Most studies show significant inequalities in health, especially between eastern and western countries, with almost all health indicators being worse in eastern countries than in Western Europe [18, 19]. The prevalence rates of diabetes mellitus, high blood pressure, obesity, and tobacco use are higher in Eastern Europe compared to Western Europe [20]. Many factors contribute to these inequalities, including differences in health literacy, access to healthcare services, economic situation in a country, and actual national health policies [21–23]. Health inequalities between eastern and Western Europe are still high, as post-socialist countries now exhibit greater disparities than western countries [20]. The inequalities appear to be higher in Eastern European regions than in Western Europe, most specifically for mental disorders and cancers. A study reported lower health inequalities in mortality in certain southern European countries and significant disparities prevalent in the eastern and Baltic regions [16]. Geographical health inequalities often mirror underlying disparities in socioeconomic levels, where wealthier countries tend to exhibit better health outcomes [22]. Efforts to mitigate these disparities could focus on enhancing educational opportunities, income distribution, health-related behaviors, and access to healthcare [24].

It is important to take differences between males and females into account when investigating health inequalities [25]. In Europe, even though NCDs are accountable for the highest burden of disease both for males and females, there are differences in their exposure to risk factors, social determinants of health, and access to health care services [25]. Men smoke and consume alcohol more than women. Furthermore, women are more prone to engage in preventive behavior, and have a higher intake of fruits and vegetables [26–28]. A number of EU level and national policies are being

developed to address sex inequalities, optimizing equality in public services and even tackling women's unpaid care work [29–31].

In the EU, which consists of high-income countries (except Bulgaria, which is upper middle income) [32], the high disease burden of NCDs has been on the political agenda for more than 30 years [33]. The EU has considerable competence in the field of health; however, the EU has no legislative power over member states' healthcare systems [34, 35]. Disease prevention and early detection are also essentially a competency of national authorities. Nevertheless, there are several EU initiatives, such as the "Healthier together – EU non-communicable diseases initiative" aiming to identify and implement effective policies in order to tackle NCDs [31]. The European Commission is determined to support EU Member States in their efforts to achieve the target of reducing NCD mortality under the Sustainable Development Goal (SDG) 3.4: "By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being" [36]. However, in fact, according to the 2030 Agenda for Sustainable Development adopted by the UN in 2015, only a slight reduction in NCD mortality was achieved by 2020 and efforts to tackle NCDs must be redoubled [37]. The slow progress was painfully highlighted by the exceptionally high COVID-19 mortality rate among individuals living with certain types of NCDs [38, 39].

The Global Burden of Disease (GBD) study provides a tool for quantifying health losses from hundreds of diseases, injuries and risk factors, under the leadership of the Institute for Health Metrics and Evaluation (IHME). Estimates of the GBD help policy makers understand the nature of their country's health challenges as well as the extent of health inequalities, especially in countries where subnational GBD estimates are available [40, 41]. The disability-adjusted life year (DALY) metric was created and first published in the GBD 1990 study [42] in order to quantify health effects while integrating information on mortality, morbidity, and disability [43]. Previous GBD studies reported that NCDs were accountable for 87% of disease burden in member states of the EU. The high disease burden underlines the immense rise of years lived with conditions such as ischemic heart disease, stroke, and depressive disorder [31, 44]. Furthermore, the top four risk factors attributable to DALY of NCDs are high systolic blood pressure (14.57%), smoking (11.54%), high fasting plasma glucose (10.4%), and high body-mass index (9.91%) [45]. In the EU, the change of age-standardized DALY rate between 2007 and 2017 for the top four risk factors were respectively: -22.6, -18.3, -5.7, and -9.7 [46].

Given the lack of studies giving insights into health inequalities related to NCDs in the countries of the European Economic Area (EEA), the overall goal of the present systematic analysis of GBD DALY estimates was to determine health inequalities in age-standardized DALY rate for NCDs overall and 12 specific NCDs across 30 EEA countries between 1990 and 2019. Accordingly, the objectives were to 1) provide a description of age-standardized NCDs DALY rate by country and sex for 2019; 2) present an age-standardized NCDs DALY rate for each country between 1990 and 2019 by sex, 3) determine age-standardized NCDs DALY rate ratios by country and sex between 1990 and 2019, and 4) assess health inequalities of NCDs by calculating Gini coefficient (GC) and Slope Index of Inequality (SII) between 1990 and 2019.

Material and methods

Study design and data source

This study is a secondary analysis of age-standardized DALY rate per 100,000 population of NCDs over a 30-year follow-up period—from 1990 to 2019 – of the GBD 2019 study [47]. One DALY should be interpreted as one lost year of healthy life. DALYs are calculated by adding Years of Life Lost (YLL), a measure of healthy time lost due to premature mortality, and Years Lived with Disability (YLDs), a measure of healthy time lost due to living with disease or injury. We retrieved age-standardized NCD DALY rate by sex, country, and year, using GBD 2019 interactive data visualization tool 'GBD Compare' [48] and 'GBD Results' [49]. The GBD 2019 study offers an extensive global, regional, and national data source for 204 countries, including 30 Member States of EEA (in 2019). A wide-ranging source of estimates is available for 369 diseases and injuries, 286 causes of death, 3484 sequelae, 87 risk factors, 23 age groups, both sexes, for a time-range from 1990 to 2019 [18, 50–52]. A detailed description of the GBD methods to calculate DALYs is given by prior publication [47].

Since the prevalence and incidence of NCDs vary by age, we have chosen to perform our analysis by using global age-standardized rates provided by the GBD tool. Age-standardized rates allow comparing health outcomes across countries and time, are consequently often used for benchmarking disease burden studies [18]. Specific data were analyzed separately for males and females. Age-standardized DALYs per 100,000 population was used to assess the total amount of healthy life lost due to NCDs level 1 and 2.

Categorization of non-communicable diseases

The GBD database organizes the included conditions in 4 different hierarchical category levels. The first level is divided into Group I: communicable, maternal, neonatal, and nutritional diseases; Group II: NCDs; and Group III: injuries. Level 2 diseases are the subdivisions of level 1 groups, there are 22 disease and injury aggregate groupings. Level 3 and 4 include specific causes. For certain diseases, level 3 causes are the most detailed classification, while for others a more detailed categorization is defined at level 4. Our analysis was limited to NCDs at level 1 (Group I and III were excluded) and level 2: cardiovascular diseases (CVDs), chronic respiratory diseases, diabetes and kidney diseases, digestive diseases, mental disorders, musculoskeletal disorders, neoplasms, neurological disorders, sense organ diseases, skin and subcutaneous diseases, substance use disorders, and other NCDs (such as congenital birth defects, gynecological diseases, oral disorders, endocrine, metabolic, blood, and immune disorders).

Target countries

The following 30 EEA Member States were included in our study: Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of Cyprus, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. The EEA was founded by the Agreement on the European Economic Area, an international agreement allowing the extension of the EU's single market to the member countries of the European Free Trade Association (Iceland, Liechtenstein, and Norway). The United Kingdom (UK) was part of the EEA in 2019 – for this reason, we included the UK in the analysis. Since the GBD 2019 database does not report data for Liechtenstein, it was excluded from our study.

Statistical analysis

We used DALY rate ratios to compare inequalities between the 30 countries, by sex, and across time – a similar methodology was used elsewhere [18]. This ratio is calculated by dividing the age-standardized DALY rate of two countries, in which the higher-ranking is the numerator and the lower-ranking is the denominator:

$$\frac{Higher\ ranking\ age\ standardized\ DALY\ rate}{Lower\ ranking\ age\ standardized\ DALY\ rate} = Ratio$$

In order to compare the inequality between country-pairs in 2019, the DALY rate ratios are calculated for each country-pairs (higher-ranking/lower-ranking), by sex. This calculation yields 29 different DALY rate ratios for each of the countries presented. Values closer to "1" indicate equality between the two countries being compared, and values above "1" indicate inequality [18].

To determine the differences in DALY rate between 1990 and 2019 for males and females, we used annual rate of change, which is calculated using linear regression of the natural log of the mortality rate by year of death and expressed as a percentage by calculating the exponential of the β-coefficient minus one:

$$\left(exponential\left(\beta\ coef\ ficient(LN[X])\right) - 1\right) = Annual\ rate\ of\ change$$

The lower the annual rate of change, the greater the decline in the DALY rate between 1990 and 2019. Furthermore, the annual rate of change can be negative, indicating a decrease DALY rate, or positive, indicating an increase in DALY rate [47]. Maps were plotted to show changes in age-standardized level 1 NCD DALYs (annual rate changes) stratified by EEA member states and sex between 1990 and 2019.

We also calculated the DALY rate ratio for each year and each level 2 NCDs by dividing the highest-ranking country DALY rate by the lowest one of each year from 1990 to 2019. Rates closest to "1" indicate equality in diseases between countries, and rates above "1" indicate greater inequality between countries.

The GC, from the Lorenz curve family, was used to measure the DALY rate inequalities across countries. GC is used to analyze the extent in inequality between values, and how far these values are from equal distribution, in this case DALY rate. GC is usually defined based on the Lorenz curve, which plots the cumulative proportion of the DALY rate of the countries by the cumulative proportion of population. The line drawn at 45 degrees thus represents perfect equality. The GC is twice the ratio of the area that lies between the line of equality and the Lorenz curve. GC ranges from 0 to 1, in which 0 represents perfect equality and 1 means total inequality [53]. GC was calculated by Stata using ineqdeco (Stata module to calculate inequality indices with decomposition by subgroup) with bootstrap resampling to calculate 95% confidence intervals [54]. The SII was used as an additional measure of health inequality, that was used to estimate the average absolute difference in DALY rate across countries. This measure is based on the beta coefficient (slope) of the linear regression of Pen's Parade, which ranked all countries by their DALY rate from lowest to highest, with the share to the total population of the included countries. Both measures are used to estimate inequality in DALY rate across countries [53, 55].

The GBD database provides data with 95% uncertainty intervals (95% UI) which reflect the variability and potential error in the modeling process providing a range of plausible values within the true DALY rate is expected to lie [47]. The DALY rate estimates are calculated by

sampling 1000 draws of the posterior distribution. The DALY rate was reported in the present study as the mean value of the 1000 draws estimate. The 95% UI is represented by the 2.5th and 97.5th percentiles of the corresponding distribution. The 95% UI was interpreted as indicating a statistical difference if they did not overlap: if two or more countries had DALYs within the same 95% UI, they were considered to have no statistical difference.

The data was downloaded directly from GBD Results Tool and organized in Microsoft Excel [56]. All the age standardized DALY rate ratio and GC were calculated by using ineqdeco module in STATA [57]. Tables and graphs were generated via Excel [56] and the maps were designed with MapChart [58].

Results

Age-standardized NCDs DALY rate in 2019

Age-standardized DALY rates for NCDs level 1 and 2 by countries, 2019

Table 1 provides level 1 and 2 NCDs age-standardized DALY rates per 100,000 population and 95% UI for the 30 Member States of EEA. The NCDs DALY rate ranged from a high of 24,342 (95% UI: 20,406 to 28,775) in Bulgaria to a low of 14,845 (95% UI: 12,379 to 17,682) in Iceland. CVD contributed most to the NCDs DALY rate in Bulgaria with 9,570 (95% UI: 7,964 to 11,490) representing 39.3% of NCDs, followed by Romania with 6,644 (95% UI: 5,673 to 7,840) representing 32.2%, and Latvia with 6,603 (95% UI: 5,695 to 7,727) representing 32.1%. The lowest DALY rate due to CVD was observed in Iceland with 1,853 (95% UI: 1,669 to 2,032) being 12.5% of total NCDs, Spain with 1,834 (95% UI: 1,699 to 1,958) being 11.9%, and France with 1,628 (95% UI: 1,489 to 1,742) representing 10.5%. NCDs with lowest DALY rate and percentage were sense organ diseases in Sweden with 340 (95% UI: 227 to 487) and 2.2%, substance use disorders in Italy with 344 (95% UI: 255 to 445) also with 2.2%, and chronic respiratory diseases from Estonia with 354 (95% UI: 294 to 426) and 1.9%.

Age-standardized level 1 NCDs DALY rate ratios by countries and sex, 2019

The ratio of age-standardized level 1 NCDs DALY rate across countries in 2019 was close to 1.00, suggesting DALY rate across countries are close to equality (Fig. 1). It reached a maximum of 1.90 (statistically significant difference) between Bulgaria and Iceland for males. In other words, the NCDs DALY rate for males in Bulgaria was, on average, 1.9 times higher than the rate in Iceland. Overall, in males the ratio was higher in comparison to females, demonstrating greater cross-country inequalities in DALY rate for males. Compared with most other countries, the following eastern european countries had high NCD DALY rate ratios for males: Bulgaria, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia. A few ratios reached a ratio of 1.00, suggesting total equality in DALY rates between two countries: Denmark/Finland, Ireland/Austria, Spain/France, Ireland/Slovenia, Italy/Netherlands, and Poland/Slovakia.

The NCD DALY rate ratios in females reached a maximum of 1.50 between Slovenia and Bulgaria, which was the only statistically significant difference for females. In fact, Bulgaria – even in females – demonstrated the highest inequality in comparison to almost all the other EEA countries. Many comparisons between countries were reached a 1.00 ratio, such as: Italy/Finland, Lithuania/Denmark, Austria/Luxembourg, Austria/Malta, Malta/Luxembourg, UK/Latvia, Spain/France and others.

Changes in NCDs DALY rate between 1990 and 2019

Age-standardized level 1 DALY rates by countries and sex between 1990 and 2019

Figure 2 shows NCD DALY rate per 100,000 population progression for each included country over time for males and females, from 1990 to 2019. There was an overall declining trend—the NCDs DALY rate gradually decreased in all countries over the 30-year follow-up period.

For the male population, a distinct differentiation between countries exhibiting elevated DALY rates and those presenting lower values in 1990 can be observed. The countries with a high DALY rate were Hungary with 35,066 (95% UI: 33,073 to 37,161) and Bulgaria with 31,747 (95% UI: 29,430 to 34,157). Countries with a low DALY rate ranged from 25,431 (95% UI: 21,152 to 30,611) in Slovenia to 19,589 (95% UI: 17,405 to 21,931) in Iceland. Comparison of DALY rates among the female population shows a more homogenous pattern across the member states of EU, confirmed by the overlapping 95% UI. In 1990, the highest DALY rate was between Bulgaria with 23,997 (95% UI: 21,538 to 26,836) to Romania with 23,579 (95% UI: 21,253 to 26,158). The lowest DALY rate was observed for France with 17,868 (95% UI: 14,979 to 21,155).

In 1994, the highest DALY rate for both males and females were found in Latvia, Estonia and Lithuania. From 1990 to 1997, NCDs DALY rate decreased in most countries, except for Bulgaria. In 2007, for males similarly to 1994, new peaks were observed in Latvia, Estonia and Lithuania. For the females in 2007, the peak values were in Latvia, Lithuania and in Hungary.

At the end of the study period, in 2019, most countries were in the range of 28,589/15,033 DALYs for males (Bulgaria/Iceland) and 20,822/13,910 DALYs for females (Bulgaria/Slovenia) – both with statistical difference confirmed by the not overlapped 95% UI. Bulgaria consistently

Table 1 Age-standardized DALY rate per 100,000 population by NCDs and EEA Member States, 2019

Cause	Austria			Belgium			Bulgaria			Croatia			Cyprus		
	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)
NCDs	**16,239**	**(13,738–19,152)**	**(100)**	**16,513**	**(13,920–19,413)**	**(100)**	**24,342**	**(20,406–28,775)**	**(100)**	**17,974**	**(14,981–21,351)**	**(100)**	**16,599**	**(14,057–19,448)**	**(100)**
CVDs	2,408	(2,225–2,552)	(14.8)	2,021	(1,879–2,144)	(12.2)	9,570	(7,964–11,490)	(39.3)	4,267	(3,532–5,131)	(23.7)	2,939	(2,629–3,303)	(17.7)
Chronic respiratory diseases	651	(544–777)	(4.0)	879	(763–1,012)	(5.3)	693	(576–819)	(2.8)	632	(524–748)	(3.5)	864	(707–1,028)	(5.2)
Diabetes and kidney diseases	790	(654–953)	(4.9)	694	(548–873)	(4.2)	1,265	(1,039–1,516)	(5.2)	981	(775–1,229)	(5.5)	1,165	(972–1,388)	(7.0)
Digestive diseases	674	(595–768)	(4.1)	641	(580–714)	(3.9)	1,282	(1,045–1,554)	(5.3)	898	(731–1,083)	(5.0)	483	(423–555)	(2.9)
Mental disorders	1,905	(1,388–2,518)	(11.7)	1,875	(1,369–2,467)	(11.4)	1,349	(991–1,785)	(5.5)	1,451	(1,059–1,919)	(8.1)	1,915	(1,390–2,541)	(11.5)
Musculoskeletal disorders	1,971	(1,413–2,650)	(12.1)	2,042	(1,461–2,729)	(12.4)	1,544	(1,096–2,061)	(6.3)	1,600	(1,141–2,117)	(8.9)	2,225	(1,597–2,963)	(13.4)
Neoplasms	2,820	(2,682–2,968)	(17.4)	3,256	(3,096–3,421)	(19.7)	4,368	(3,485–5,458)	(17.9)	3,770	(2,989–4,719)	(21.0)	2,648	(2,366–2,944)	(16.0)
Neurological disorders	1,326	(734–2,203)	(8.2)	1,579	(775–2,769)	(9.6)	1,313	(784–2,066)	(5.4)	1,289	(732–2,047)	(7.2)	1,330	(690–2,273)	(8.0)
Sense organ diseases	392	(263–558)	(2.4)	409	(279–580)	(2.5)	618	(412–888)	(2.5)	606	(407–879)	(3.4)	397	(268–569)	(2.4)
Skin and subcutaneous diseases	711	(482–1,013)	(4.4)	730	(504–1,024)	(4.4)	454	(300–669)	(1.9)	444	(293–654)	(2.5)	719	(500–1,021)	(4.3)
Substance use disorders	659	(516–816)	(4.1)	601	(476–750)	(3.6)	384	(291–497)	(1.6)	523	(406–660)	(2.9)	358	(267–461)	(2.2)
Other NCDs	1,932	(1,486–2,487)	(11.9)	1,788	(1,348–2,322)	(10.8)	1,503	(1,189–1,904)	(6.2)	1,513	(1,157–1,950)	(8.4)	1,556	(1,184–2,026)	(9.4)
Cause	**Czechia**			**Denmark**			**Estonia**			**Finland**			**France**		
	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)
NCDs	**17,125**	**(14,441–20,203)**	**(100)**	**17,166**	**(14,672–19,955)**	**(100)**	**18,874**	**(15,777–22,305)**	**(100)**	**16,428**	**(13,963–19,205)**	**(100)**	**15,461**	**(13,059–18,230)**	**(100)**
CVDs	3,909	(3,314–4,605)	(22.8)	1,968	(1,833–2,091)	(11.5)	4,651	(3,813–5,715)	(24.6)	2,864	(2,653–3,031)	(17.4)	1,628	(1,489–1,742)	(10.5)
Chronic respiratory diseases	628	(529–728)	(3.7)	1030	(867–1,167)	(6.0)	354	(294–426)	(1.9)	618	(512–756)	(3.8)	554	(445–692)	(3.6)
Diabetes and kidney diseases	1,251	(960–1,590)	(7.3)	678	(576–798)	(4.0)	752	(600–928)	(4.0)	685	(512–889)	(4.2)	463	(383–558)	(3.0)

Table 1 (continued)

Digestive diseases	896	(748–1,062)	(5.2)	686	(616–768)	(4.0)	987	(805–1,203)	(5.2)	788	(717–873)	(4.8)	565	(512–629)	(3.7)
Mental disorders	1,385	(1,014–1,825)	(8.1)	1,794	(1,303–2,376)	(10.5)	1,573	(1,145–2,081)	(8.3)	1,887	(1,387–2,497)	(11.5)	2,045	(1,489–2,717)	(13.2)
Musculoskeletal disorders	1,548	(1,110–2,065)	(9.0)	2,485	(1,781–3,292)	(14.5)	1,510	(1,080–2,011)	(8.0)	2,037	(1,467–2,717)	(12.4)	2,055	(1,474–2,732)	(13.3)
Neoplasms	3,405	(2,813–4,137)	(19.9)	3,494	(3,304–3,675)	(20.4)	3,522	(2,774–4,417)	(18.7)	2,606	(2,442–2,778)	(15.9)	3,311	(3,133–3,473)	(21.4)
Neurological disorders	1,269	(725–2,038)	(7.4)	1,282	(712–2,110)	(7.5)	1,337	(810–2,094)	(7.1)	1,396	(763–2,301)	(8.5)	1,426	(791–2,290)	(9.2)
Sense organ diseases	595	(398–861)	(3.5)	374	(250–537)	(2.2)	642	(427–932)	(3.4)	388	(262–553)	(2.4)	402	(273–572)	(2.6)
Skin and subcutaneous diseases	454	(300–669)	(2.7)	776	(529–1,106)	(4.5)	553	(357–805)	(2.9)	748	(515–1,058)	(4.6)	843	(578–1,180)	(5.5)
Substance use disorders	515	(398–648)	(3.0)	890	(743–1,052)	(5.2)	1,646	(1,350–1,989)	(8.7)	925	(785–1,079)	(5.6)	567	(453–697)	(3.7)
Other NCDs	1,271	(947–1,677)	(7.4)	1,709	(1,290–2,218)	(10.0)	1,345	(1,009–1,758)	(7.1)	1,484	(1,114–1,945)	(9.0)	1,602	(1,228–2,056)	(10.4)
Cause	**Germany**			**Greece**			**Hungary**			**Iceland**			**Ireland**		
	DALY rate	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**
NCDs	**17,277**	**(14,710–20,233)**	**(100)**	**17,222**	**(14,700–20,068)**	**(100)**	**20,458**	**(17,350–23,915)**	**(100)**	**14,845**	**(12,379–17,682)**	**(100)**	**16,792**	**(14,166–19,735)**	**(100)**
CVDs	2,601	(2,422–2,741)	**(100)**	3,198	(3,001–3,351)	(18.6)	5,420	(4,612–6,359)	(26.5)	1,853	(1,669–2,032)	(12.5)	2,193	(1,990–2,338)	(13.1)
Chronic respiratory diseases	749	(651–857)	(15.1)	724	(611–843)	(4.2)	947	(816–1,099)	(4.6)	768	(635–936)	(5.2)	969	(830–1,128)	(5.8)
Diabetes and kidney diseases	894	(723–1,099)	(4.3)	790	(638–967)	(4.6)	1,020	(815–1,254)	(5.0)	533	(408–683)	(3.6)	622	(491–770)	(3.7)
Digestive diseases	742	(677–816)	(5.2)	470	(412–548)	(2.7)	1,269	(1,063–1,489)	(6.2)	355	(305–411)	(2.4)	465	(413–533)	(2.8)
Mental disorders	1,899	(1,368–2,515)	(4.3)	2,260	(1,664–2,968)	(13.1)	1,394	(1,014–1,851)	(6.8)	1,761	(1,283–2,342)	(11.9)	2,202	(1,612–2,884)	(13.1)
Musculoskeletal disorders	2,211	(1,583–2,927)	(11.0)	2,031	(1,463–2,694)	(11.8)	1,605	(1,149–2,135)	(7.8)	2,253	(1,593–3,017)	(15.2)	2,273	(1,644–3,028)	(13.5)
Neoplasms	3,221	(3,063–3,368)	(12.8)	3,300	(3,134–3,471)	(19.2)	4,551	(3,772–5,494)	(22.2)	2,690	(2,449–2,963)	(18.1)	3,049	(2,859–3,244)	(18.2)
Neurological disorders	1,539	(811–2,545)	(18.6)	1,330	(662–2,277)	(7.7)	1,260	(729–2,007)	(6.2)	1,385	(749–2,286)	(9.3)	1,404	(766–2,318)	(8.4)

Table 1 (continued)

Sense organ diseases	393	(267–559)	(8.9)	419	(285–594)	(2.4)	614	(412–885)	(3.0)	399	(269–570)	(2.7)	397	(269–569)	(2.4)
Skin and subcutaneous diseases	717	(485–1,039)	(2.3)	677	(465–970)	(3.9)	489	(324–716)	(2.4)	753	(515–1,064)	(5.1)	728	(500–1,031)	(4.3)
Substance use disorders	618	(501–751)	(4.1)	432	(333–540)	(2.5)	490	(378–619)	(2.4)	672	(544–822)	(4.5)	824	(654–1,007)	(4.9)
Other NCDs	1,692	(1,287–2,189)	(3.6)	1,591	(1,221–2,077)	(9.2)	1,399	(1,084–1,781)	(6.8)	1,423	(1,052–1,872)	(9.6)	1,666	(1,283–2,137)	(9.9)
Cause	**Italy**			**Latvia**			**Lithuania**			**Luxembourg**			**Malta**		
	DALY rate	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**	**DALY rate**	**95%UI**	**(%)**
NCDs	**15,753**	**(13,159–18,646)**	**(100)**	**20,566**	**(17,662–23,817)**	**(100)**	**20,070**	**(17,138–23,241)**	**(100)**	**15,740**	**(13,161–18,606)**	**(100)**	**15,953**	**(13,411–18,839)**	**(100)**
CVDs	2,032	(1,854–2,156)	(12.9)	6,603	(5,695–7,727)	(32.1)	5,824	(4,926–6,939)	(29.0)	1,981	(1,766–2,213)	(12.6)	2,511	(2,256–2,770)	(15.7)
Chronic respiratory diseases	539	(454–635)	(3.4)	391	(320–484)	(1.9)	424	(353–510)	(2.1)	787	(653–953)	(5.0)	674	(547–828)	(4.2)
Diabetes and kidney diseases	814	(658–992)	(5.2)	746	(600–923)	(3.6)	547	(434–683)	(2.7)	804	(618–1,020)	(5.1)	919	(744–1,129)	(5.8)
Digestive diseases	644	(553–752)	(4.1)	1,069	(903–1,256)	(5.2)	1,447	(1,215–1,729)	(7.2)	610	(531–700)	(3.9)	429	(371–495)	(2.7)
Mental disorders	1,954	(1,434–2,586)	(12.4)	1,614	(1,184–2,122)	(7.8)	1,716	(1,256–2,262)	(8.6)	1,850	(1,352–2,442)	(11.8)	1,903	(1,387–2,522)	(11.9)
Musculoskeletal disorders	2,184	(1,562–2,889)	(13.9)	1,531	(1,097–2,054)	(7.4)	1,496	(1,065–1,988)	(7.5)	2,141	(1,538–2,848)	(13.6)	2,224	(1,600–2,953)	(13.9)
Neoplasms	2,976	(2,823–3,081)	(18.9)	3,631	(3,056–4,324)	(17.7)	3,573	(2,929–4,312)	(17.8)	2,933	(2,618–3,306)	(18.6)	2,604	(2,358–2,889)	(16.3)
Neurological disorders	1,472	(740–2,567)	(9.3)	1,260	(758–1,994)	(6.1)	1,242	(748–1,967)	(6.2)	1,366	(753–2,213)	(8.7)	1,329	(711–2,222)	(8.3)
Sense organ diseases	530	(367–733)	(3.4)	691	(465–989)	(3.4)	688	(463–989)	(3.4)	380	(253–547)	(2.4)	405	(274–576)	(2.5)
Skin and subcutaneous diseases	733	(497–1,050)	(4.7)	419	(286–615)	(2.0)	441	(296–648)	(2.2)	728	(501–1,039)	(4.6)	748	(528–1,028)	(4.7)
Substance use disorders	344	(255–445)	(2.2)	1,056	(864–1,267)	(5.1)	1,053	(879–1,242)	(5.2)	664	(530–820)	(4.2)	466	(360–591)	(2.9)
Other NCDs	1,532	(1,156–1,999)	(9.7)	1,554	(1,192–1,986)	(7.6)	1,619	(1,242–2,073)	(8.1)	1,496	(1,108–1,976)	(9.5)	1,740	(1,350–2,224)	(10.9)

Table 1 (continued)

Cause	Netherlands			Norway			Poland			Portugal			Romania		
	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)
NCDs	**16,215**	**(13,797–19,002)**	**(100)**	**15,642**	**(13,123–18,527)**	**(100)**	**18,313**	**(15,640–21,393)**	**(100)**	**16,664**	**(14,085–19,599)**	**(100)**	**20,643**	**(17,686–23,857)**	**(100)**
CVDs	1,883	(1,737–2,009)	(11.6)	1,901	(1,747–2,027)	(12.2)	4,183	(3,595–4,832)	(22.8)	2,150	(1,997–2,282)	**(100)**	6,644	(5,673–7,840)	(32.2)
Chronic respiratory diseases	977	(816–1,136)	(6.0)	889	(719–1,049)	(5.7)	651	(541–783)	(3.6)	861	(706–1,064)	(12.9)	714	(602–851)	(3.5)
Diabetes and kidney diseases	637	(519–775)	(3.9)	650	(516–807)	(4.2)	951	(752–1,160)	(5.2)	980	(798–1,199)	(5.2)	781	(629–961)	(3.8)
Digestive diseases	438	(394–491)	(2.7)	510	(431–606)	(3.3)	1,033	(874–1,211)	(5.6)	624	(571–690)	(5.9)	1,501	(1,269–1,782)	(7.3)
Mental disorders	2,069	(1,519–2,734)	(12.8)	1,945	(1,427–2,580)	(12.4)	1,259	(930–1,651)	(6.9)	2,317	(1,672–3,082)	(3.7)	1,368	(1,007–1,805)	(6.6)
Musculoskeletal disorders	2,001	(1,435–2,655)	(12.3)	1,879	(1,333–2,519)	(12.0)	1,629	(1,167–2,169)	(8.9)	2,256	(1,628–2,974)	(13.9)	1,579	(1,122–2,113)	(7.6)
Neoplasms	3,614	(3,411–3,796)	(22.3)	2,844	(2,705–2,968)	(18.2)	4,192	(3,527–4,913)	(22.9)	3,135	(2,980–3,302)	(13.5)	3,998	(3,275–4,799)	(19.4)
Neurological disorders	1,414	(787–2,320)	(8.7)	1,474	(794–2,439)	(9.4)	1,337	(800–2,121)	(7.3)	1,291	(668–2,200)	(18.8)	1,249	(703–2,034)	(6.1)
Sense organ diseases	371	(249–538)	(2.3)	470	(317–664)	(3.0)	637	(431–912)	(3.5)	413	(283–589)	(7.7)	623	(416–896)	(3.0)
Skin and subcutaneous diseases	721	(497–1,019)	(4.4)	716	(484–1,022)	(4.6)	460	(307–676)	(2.5)	733	(504–1,038)	(2.5)	421	(281–624)	(2.0)
Substance use disorders	428	(325–538)	(2.6)	668	(555–790)	(4.3)	765	(609–934)	(4.2)	477	(344–634)	(4.4)	361	(274–463)	(1.7)
Other NCDs	1,663	(1,263–2,132)	(10.3)	1,697	(1,271–2,213)	(10.9)	1,216	(941–1,582)	(6.6)	1,428	(1,086–1,855)	(2.9)	1,405	(1,087–1,811)	(6.8)
Cause	**Slovakia**			**Slovenia**			**Spain**			**Sweden**			**United Kingdom**		
	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)	DALY rate	95%UI	(%)
NCDs	**18,755**	**(15,624–22,338)**	**(100)**	**15,164**	**(12,511–18,272)**	**(100)**	**15,454**	**(13,046–18,341)**	**(100)**	**15,351**	**(12,978–18,096)**	**(100)**	**18,001**	**(15,317–21,079)**	**(100)**
CVDs	5,134	(4,207–6,179)	(27.4)	2,546	(2,068–3,143)	(16.8)	1,834	(1,699–1,958)	(11.9)	2,329	(2,149–2,483)	15.2)	2,362	(2,216–2,477)	(13.1)
Chronic respiratory diseases	476	(395–569)	(2.5)	505	(407–613)	(3.3)	752	(649–863)	(4.9)	786	(634–963)	(5.1)	1,187	(1,004–1,392)	(6.6)

Table 1 (continued)

Diabetes and kidney diseases	848	(666–1,049)	(4.5)	697	(516–888)	(4.6)	789	(608–999)	(5.1)	615	(502–746)	(4.0)	780	(592–993)	(4.3)
Digestive diseases	1,242	(996–1,555)	(6.6)	864	(697–1,078)	(5.7)	551	(500–614)	(3.6)	466	(410–535)	(3.0)	889	(794–1,008)	(4.9)
Mental disorders	1,373	(1,015–1,817)	(7.3)	1,462	(1,071–1,929)	(9.6)	2,192	(1,614–2,905)	(14.2)	2,017	(1,474–2,653)	(13.1)	1,959	(1,437–2,590)	(10.9)
Musculoskeletal disorders	1,541	(1,099–2,049)	(8.2)	1,521	(1,081–2,033)	(10.0)	1,831	(1,298–2,442)	(11.8)	2,036	(1,472–2,692)	(13.3)	2,314	(1,671–3,050)	(12.9)
Neoplasms	3,762	(2,974–4,712)	(20.1)	3,341	(2,615–4,278)	(22.0)	2,977	(2,820–3,120)	(19.3)	2,672	(2,550–2,783)	(17.4)	3,302	(3,164–3,403)	(18.3)
Neurological disorders	1,281	(739–2,049)	(6.8)	1,249	(727–2,025)	(8.2)	1,350	(700–2,272)	(8.7)	1,321	(692–2,210)	(8.6)	1,434	(826–2,318)	(8.0)
Sense organ diseases	606	(400–878)	(3.2)	568	(377–825)	(3.7)	538	(370–749)	(3.5)	340	(227–487)	(2.2)	503	(342–711)	(2.8)
Skin and subcutaneous diseases	451	(296–662)	(2.4)	451	(297–665)	(3.0)	698	(481–986)	(4.5)	692	(469–985)	(4.5)	736	(505–1,043)	(4.1)
Substance use disorders	477	(356–616)	(2.5)	621	(490–775)	(4.1)	469	(354–605)	(3.0)	692	(569–818)	(4.5)	924	(730–1,136)	(5.1)
Other NCDs	1,564	(1,204–2,023)	(8.3)	1,337	(997–1,772)	(8.8)	1,472	(1,129–1,900)	(9.5)	1,386	(1,048–1,799)	(9.0)	1,609	(1,254–2,037)	(8.9)

Legend: *%* percentage, *UI* Uncertainty Interval, *NCDs* noncommunicable diseases, and *CVDs* cardiovascular diseases

Countries		Austria	Belgium	Bulgaria	Croatia	Cyprus	Czechia	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Iceland	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Norway	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK
	Female	16009	16314	20822	16161	16589	15642	17194	16414	15845	15322	17077	16777	17989	14816	16896	15771	17803	17208	15964	16000	16545	15894	15821	16190	17920	16769	13910	15301	15707	17766
	Male	16716	16931	28589	20315	16599	19000	17301	22234	17243	15831	17713	17835	23763	15033	16779	15977	24497	24160	15675	16136	16044	15551	21445	17412	23955	21341	16812	15864	15115	18370
Austria	16009	16716	ref	1.02	1.30	1.01	1.04	1.02	1.07	1.03	1.01	1.04	1.07	1.05	1.12	1.08	1.06	1.02	1.11	1.07	1.00	1.00	1.03	1.01	1.01	1.01	1.12	1.05	1.15	1.05	1.02	1.11
Belgium	16314	16931	1.01	ref	1.28	1.01	1.02	1.04	1.05	1.01	1.03	1.06	1.05	1.03	1.10	1.10	1.04	1.03	1.09	1.05	1.02	1.02	1.01	1.03	1.03	1.01	1.10	1.03	1.17	1.07	1.04	1.09
Bulgaria	20822	28589	***1.71***	***1.69***	ref	1.29	1.26	1.33	1.21	1.27	1.31	1.36	1.22	1.24	1.16	1.41	1.23	1.32	1.17	1.21	1.30	1.30	1.26	1.31	1.32	1.29	1.16	1.24	***1.50***	1.36	1.33	1.17
Croatia	16161	20315	1.22	1.20	1.41	ref	1.03	1.03	1.06	1.02	1.02	1.05	1.06	1.04	1.11	1.09	1.05	1.02	1.10	1.06	1.01	1.01	1.02	1.02	1.02	1.00	1.11	1.04	1.16	1.06	1.03	1.10
Cyprus	16589	16599	1.01	1.02	***1.72***	1.22	ref	1.06	1.04	1.01	1.05	1.08	1.03	1.01	1.08	1.12	1.02	1.05	1.07	1.04	1.04	1.04	1.00	1.04	1.05	1.02	1.08	1.01	1.19	1.08	1.06	1.07
Czechia	15642	19000	1.14	1.12	***1.50***	1.07	1.14	ref	1.10	1.05	1.01	1.02	1.09	1.07	1.15	1.06	1.08	1.01	1.14	1.10	1.02	1.02	1.06	1.02	1.01	1.04	1.15	1.07	1.12	1.02	1.00	1.14
Denmark	17194	17301	1.03	1.02	***1.65***	1.17	1.04	1.10	ref	1.05	1.09	1.12	1.01	1.02	1.05	1.16	1.02	1.09	1.04	1.00	1.08	1.07	1.04	1.08	1.09	1.06	1.04	1.03	1.24	1.12	1.09	1.03
Estonia	16414	22234	***1.33***	1.31	1.29	1.09	1.34	1.17	1.29	ref	1.04	1.07	1.04	1.02	1.10	1.11	1.03	1.04	1.08	1.05	1.03	1.03	1.01	1.03	1.04	1.01	1.09	1.02	1.18	1.07	1.05	1.08
Finland	15845	17243	1.03	1.02	***1.66***	1.18	1.04	1.10	1.00	1.29	ref	1.03	1.08	1.06	1.14	1.07	1.07	1.00	1.12	1.09	1.01	1.01	1.04	1.00	1.00	1.02	1.13	1.06	1.14	1.04	1.01	1.12
France	15322	15831	1.06	1.07	***1.81***	1.28	1.05	1.20	1.09	***1.40***	1.09	ref	1.11	1.09	1.17	1.03	1.10	1.03	1.16	1.12	1.04	1.04	1.08	1.04	1.03	1.06	1.17	1.09	1.10	1.00	1.03	1.16
Germany	17077	17713	1.06	1.05	***1.61***	1.15	1.07	1.07	1.02	1.26	1.03	1.12	ref	1.02	1.05	1.15	1.01	1.08	1.04	1.01	1.07	1.07	1.03	1.07	1.08	1.05	1.05	1.02	1.23	1.12	1.09	1.04
Greece	16777	17835	1.07	1.05	***1.60***	1.14	1.07	1.07	1.03	1.25	1.03	1.13	1.01	ref	1.07	1.13	1.01	1.06	1.06	1.03	1.05	1.05	1.01	1.06	1.06	1.04	1.07	1.00	1.21	1.10	1.07	1.06
Hungary	17989	23763	***1.42***	***1.40***	1.20	1.17	***1.43***	1.25	***1.37***	1.07	***1.38***	***1.50***	**1.34**	***1.33***	ref	1.21	1.06	1.14	1.01	1.05	1.13	1.12	1.09	1.13	1.14	1.11	1.00	1.07	1.29	1.18	1.15	1.01
Iceland	14816	15033	1.11	1.13	***1.90***	1.35	1.10	1.26	1.15	***1.48***	1.15	1.05	1.18	1.19	***1.58***	ref	1.14	1.06	1.20	1.16	1.08	1.08	1.12	1.07	1.07	1.09	1.21	1.13	1.07	1.03	1.06	1.20
Ireland	16896	16779	1.00	1.01	***1.70***	1.21	1.01	1.13	1.03	1.33	1.03	1.06	1.06	1.06	***1.42***	1.12	ref	1.07	1.05	1.02	1.06	1.06	1.02	1.06	1.07	1.04	1.06	1.01	1.21	1.10	1.08	1.05
Italy	15771	15977	1.05	1.06	***1.79***	1.27	1.04	1.19	1.08	1.39	1.08	1.01	1.11	1.12	***1.49***	1.06	1.05	ref	1.13	1.09	1.01	1.01	1.05	1.01	1.00	1.03	1.14	1.06	1.13	1.03	1.00	1.13
Latvia	17803	24497	***1.47***	***1.45***	1.17	1.21	***1.48***	1.29	***1.42***	1.10	***1.42***	***1.55***	***1.38***	***1.37***	1.03	***1.63***	***1.46***	***1.53***	ref	1.03	1.12	1.11	1.08	1.12	1.13	1.10	1.01	1.06	1.28	1.16	1.13	1.00
Lithuania	17208	24160	***1.45***	***1.43***	1.18	1.19	***1.46***	1.27	***1.40***	1.09	***1.40***	***1.53***	***1.36***	***1.35***	1.02	***1.61***	***1.44***	***1.51***	1.01	ref	1.08	1.08	1.04	1.08	1.09	1.06	1.04	1.03	1.24	1.12	1.10	1.03
Luxembourg	15964	15675	1.07	1.08	***1.82***	1.30	1.06	1.21	1.10	***1.42***	1.10	1.01	1.13	1.14	***1.52***	1.04	1.07	1.02	***1.56***	***1.54***	ref	1.00	1.04	1.00	1.01	1.01	1.12	1.05	1.15	1.04	1.02	1.11
Malta	16000	16136	1.04	1.05	***1.77***	1.26	1.03	1.18	1.07	1.38	1.07	1.02	1.10	1.11	***1.47***	1.07	1.04	1.01	***1.52***	***1.50***	1.03	ref	1.03	1.01	1.01	1.12	1.05	1.15	1.05	1.02	1.11
Netherlands	16545	16044	1.04	1.06	***1.78***	1.27	1.03	1.18	1.08	***1.39***	1.07	1.01	1.10	1.11	***1.48***	1.07	1.05	1.00	***1.53***	***1.51***	1.02	1.01	ref	1.04	1.05	1.02	1.08	1.01	1.19	1.08	1.05	1.07
Norway	15894	15551	1.07	1.09	***1.84***	1.31	1.07	1.22	1.11	***1.43***	1.11	1.02	1.14	1.15	***1.53***	1.03	1.08	1.03	***1.58***	***1.55***	1.01	1.04	1.03	ref	1.00	1.02	1.13	1.06	1.14	1.04	1.01	1.12
Poland	15821	21445	1.28	1.27	1.33	1.06	1.29	1.13	1.24	1.04	1.24	1.35	1.21	1.20	1.11	***1.43***	1.28	1.34	1.14	1.13	1.37	1.33	1.34	1.38	ref	1.02	1.13	1.06	1.14	1.03	1.01	1.12
Portugal	16190	17412	1.04	1.03	***1.64***	1.17	1.05	1.09	1.01	1.28	1.01	1.10	1.02	1.02	***1.36***	1.16	1.04	1.09	***1.41***	***1.39***	1.11	1.08	1.09	1.12	1.23	ref	1.11	1.04	1.16	1.06	1.03	1.10
Romania	17920	23955	***1.43***	***1.41***	1.19	1.18	***1.44***	1.26	***1.38***	1.08	***1.39***	***1.51***	***1.35***	***1.34***	1.01	***1.59***	***1.43***	***1.50***	1.02	1.01	***1.53***	***1.48***	***1.49***	***1.54***	1.12	1.38	ref	1.07	1.29	1.17	1.14	1.01
Slovakia	16769	21341	1.28	1.26	1.34	1.05	1.29	1.12	1.23	1.04	1.24	1.35	1.20	1.20	1.11	***1.42***	1.27	1.34	1.15	1.13	1.36	1.32	1.33	1.37	1.00	1.23	1.12	ref	1.21	1.10	1.07	1.06
Slovenia	13910	16812	1.01	1.01	***1.70***	1.21	1.01	1.13	1.03	1.32	1.03	1.06	1.05	1.06	***1.41***	1.12	1.00	1.05	***1.46***	***1.44***	1.07	1.04	1.05	1.08	1.28	1.04	***1.42***	1.27	ref	1.10	1.13	1.28
Spain	15301	15864	1.05	1.07	***1.80***	1.28	1.05	1.20	1.09	***1.40***	1.09	1.00	1.12	1.12	***1.50***	1.06	1.06	1.01	***1.54***	***1.52***	1.01	1.02	1.01	1.02	1.35	1.10	***1.51***	1.35	1.06	ref	1.03	1.16
Sweden	15707	15115	1.11	1.12	***1.89***	1.34	1.10	1.26	1.14	***1.47***	1.14	1.05	1.17	1.18	***1.57***	1.01	1.11	1.06	***1.62***	***1.60***	1.04	1.07	1.06	1.03	***1.42***	1.15	***1.58***	***1.41***	1.11	1.05	ref	1.13
UK	17766	18370	1.10	1.09	***1.56***	1.11	1.11	1.03	1.06	1.21	1.07	1.16	1.04	1.03	1.29	1.22	1.09	1.15	1.33	1.32	1.17	1.14	1.14	1.18	1.17	1.06	1.30	1.16	1.09	1.16	1.22	ref

Fig. 1 Ratio of age-standardized level 1 NCDs DALY rates for EEA Member States by sex, 2019. Legend: blue color represents ratios closer to 1 (equality), and red color represents ratios further from 1 (inequality). Ratios in bold and underlined represent statistical difference between DALY rate of compared countries (95% UI not overlapping). Ratios for females are above the diagonal line, and for males are under the line

maintained the highest DALY rate ratios for both sexes, surpassing other countries by a significant margin.

YLL rates also decreased in all countries and showed a high degree of similarity with the DALYs, except for the 95% UI, which was narrower. On the contrary, YLD values in both country groups were close to the plateau, for both sexes. The 95% UI for YLD was very wide for both sexes, indicating that there is little statistical difference in YLD rates between countries (Additional file 1).

Annual rate of change in age-standardized NCDs DALY rates

Figure 3 shows that the level of change in females ranged from -0.12 (95% UI: -0.10 to -0.15) in the Netherlands to -0.28 (95% UI: -0.17 to -0.40) in Slovenia and (95% UI: -0.21 to -0.35) Poland. The change was larger in males, ranging from -0.10 (95% UI: 0.06 to -0.23) in Bulgaria to -0.40 (95% UI: -0.32 to -0.47) in Czechia.

For females, countries with the lowest rates ranged from -0.27 and -0.28 in (Poland, Slovakia, Cyprus and Czechia). Countries with the highest rates of change varied from -0.15 to -0.12 (Sweden, France, Greece, Bulgaria and the Netherlands).

Overall, males had larger reductions in the NCD DALY rates, since 18 countries ranged between -0.29 to -0.40, compared to the lowest value for females of -0.28. The lowest rates of change for males were observed in Czechia, Luxembourg, Slovenia, from -0.34 to -0.40. Whereas the countries with the smaller average reduction in DALY rates (between -0.10 and -0.18) were Bulgaria, Greece and Lithuania. The level 2 NCDs annual rate of change of DALY rates by country and sex are presented in the Additional file 2, which focuses on 5 diseases with the highest DALY rate ratio: CVD, chronic respiratory diseases, diabetes and kidney diseases, digestive diseases and substance use disorders.

NCDs DALYs rate ratios by level 2 NCD cause of disease

The age-standardized level 2 NCD DALY rate ratio by year between 1990 and 2019 is presented in Fig. 4.

From 1990 through 2019, five NCDs had consistent high DALY rate ratios of 2.68 or higher, namely digestive diseases, diabetes and kidney diseases, substance use disorders, CVDs, and chronic respiratory diseases. For CVDs, the DALY ratio increased from 3.66 in 1990 to 5.88 in 2019, whereas for digestive diseases and diabetes and kidney diseases a decrease in DALY rate ratio was observed between 1990 and 2019.

For NCDs, musculoskeletal disorders, mental disorders, neoplasms, and sense organ diseases the DALY rate ratio was consistently lower than 2.23 between 1990 and 2019, with slight changes in ranking of the diseases according to DALY rate ratio over time.

Assessing health inequalities in NCDs by using Gini coefficient and Slope Index of Inequality

For level 1 NCDs, low inequalities according to the GC between countries were found. While the lowest GC were found between 2017 and 2019, from 0.064 (95% CI: 0.044 to 0.083) to 0.063 (95% CI: 0.040 0.086), the highest GC was observed in 1994, 1995, and 2007, which were 0.085 (95% CI: 0.065 to 0.106), 0.084 (95% CI: 0.067 to

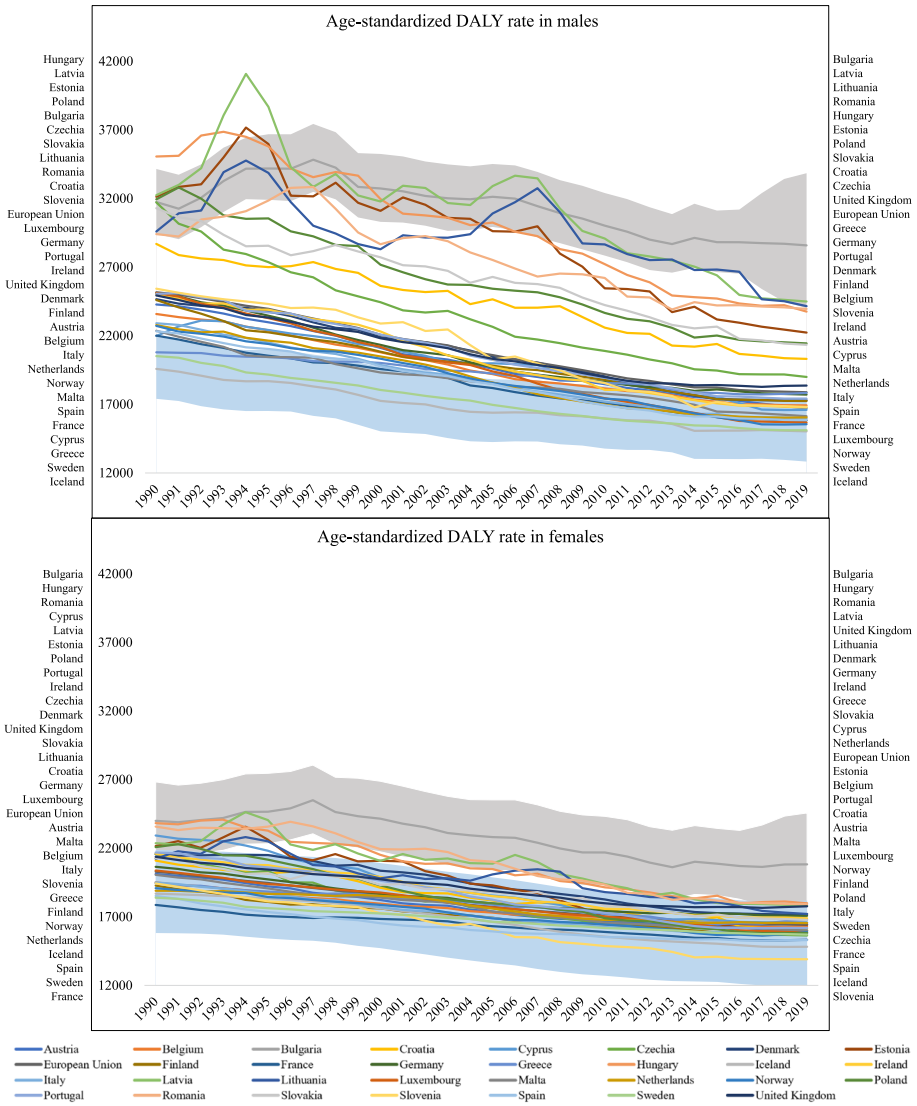

Fig. 2 Age-standardized level 1 NCDs DALY rates by EEA Member States and sex, 1990–2019. Legend: UI 95% for the overall highest (Bulgaria) and lowest (Iceland) DALY rate are shown in grey and blue shaded band, respectively. The order of the country lines within the graphs corresponds to the order of the country labels next to each graph

0.101), and 0.080 (95% CI: 0.052 to 0.108), respectively; as shown in Fig. 5.

The highest GCs were observed for CVD, chronic respiratory diseases, diabetes and kidney diseases, digestive diseases, and substance use disorders. CVD showed an increasing GC value, from 0.191 in 1990 to 0.278 (95% CI: 0.214 to 0.342) in 2019. A similar pattern was found for substance use disorders, although it was lower for the same period: 0.184 (95% CI: 0.140 to 0.228) and 0.212 (95% CI: 0.161 to 0.263). A more stable, but still high, GC was found for digestive diseases, in which it ranged from 0.217 (95% CI: 0.162 to 0.273) to 0.224 (95% CI: 0.185 to 0.262). Even though diabetes and kidney diseases were the second highest level 2 NCDs in 1990, it progressively decreased to the fifth position in 2019, going from 0.194 (95% CI: 0.137 to 0.251) to 0.133 (95% CI: 0.106 to 0.160). Chronic respiratory diseases were in a range between 1990 with 0.145 and 2019 with 0.152 (95% CI: 0.113 to 0.191). Mental disorders, musculoskeletal disorders, neoplasms, sense organ diseases, skin and subcutaneous diseases, neurological disorders and other NCDs, had lower values, between 0.026 (95% CI: 0.020 to 0.032) to 0.125 (95% CI: 0.112 to 0.139) throughout the 30 years' follow-up period.

Figure 6 and Additional file 3 show that the SII was highest for level 1 NCDs, which was 0.851 (95% CI: 0.730–0.972)

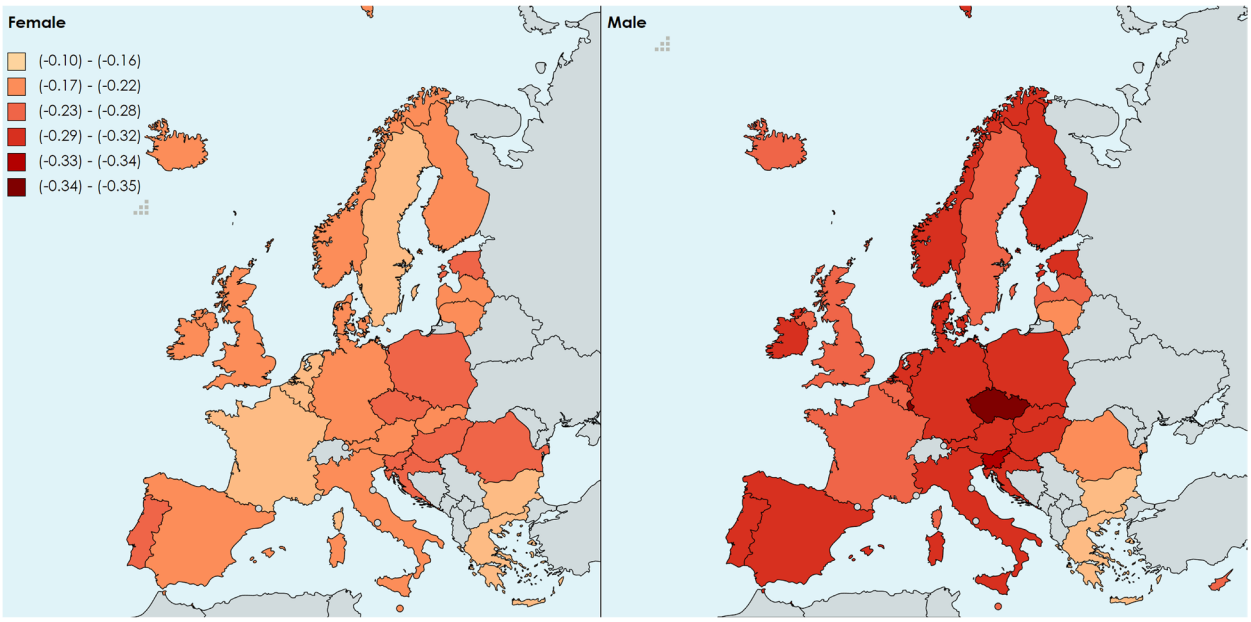

Fig. 3 Age-standardized level 1 NCDs DALY annual rate of change, 1990–2019

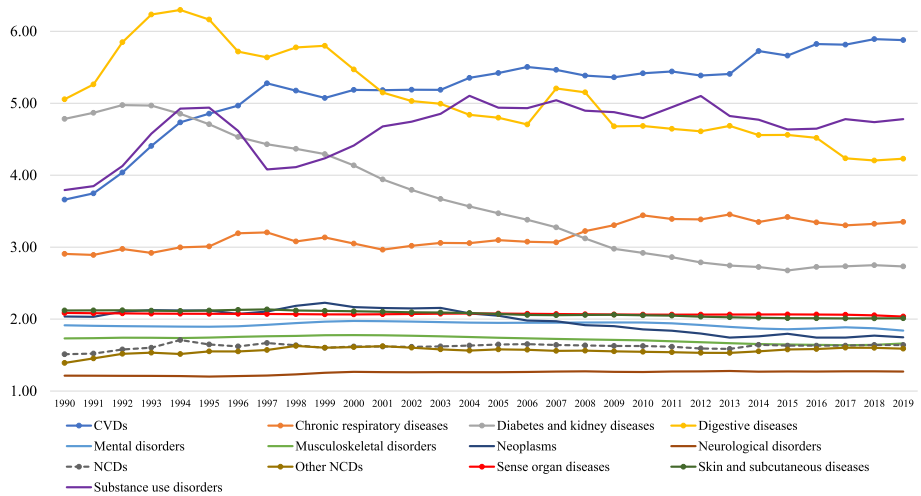

Fig. 4 Age-standardized DALY rate ratio by level 2 cause of disease between 1990 and 2019. Legend: Ratio is calculated for each NCD at level 2 by dividing the highest-ranking DALY rate by the lowest-ranking per year of the study period. NCDs: noncommunicable diseases and CVDs: cardiovascular diseases

in 1990 and 0.592 (95% CI: 0.470–0.715) in 2019, with two peaks in 1994 and 2007, 0.951 (95% CI: 0.781–1.121) and 0.871 (95% CI: 0.679–1.063), respectively.

CVDs followed the level 1 NCDs pattern closely in 1990, 1994, 2007, and 2019: 0.852 (0.708 to 0.997), 0.997 (0.776 to 1.245), 0.784 (0.569 to 1.000), and 0.531 (0.381 to 0.681), respectively. Another level 2 NCD with the elevated SII was neoplasms, however, it showed a much lower and steady inequality trend across the years, from 0.161 (0.136 to 0.185) in 1990 to 0.132 (0.111 to 0.153) in 2019. For a group of level 2 diseases, the SII was very close to zero over the follow-up years, ranging from 0.021 (neurological disorders in 1990) to 0.115 (digestive diseases in 1992) – these were chronic respiratory diseases, diabetes and kidney diseases, digestive diseases, mental disorders, musculoskeletal disorders, neurological disorders, substance use disorders, other NCDs, sense organ diseases, and skin and subcutaneous diseases.

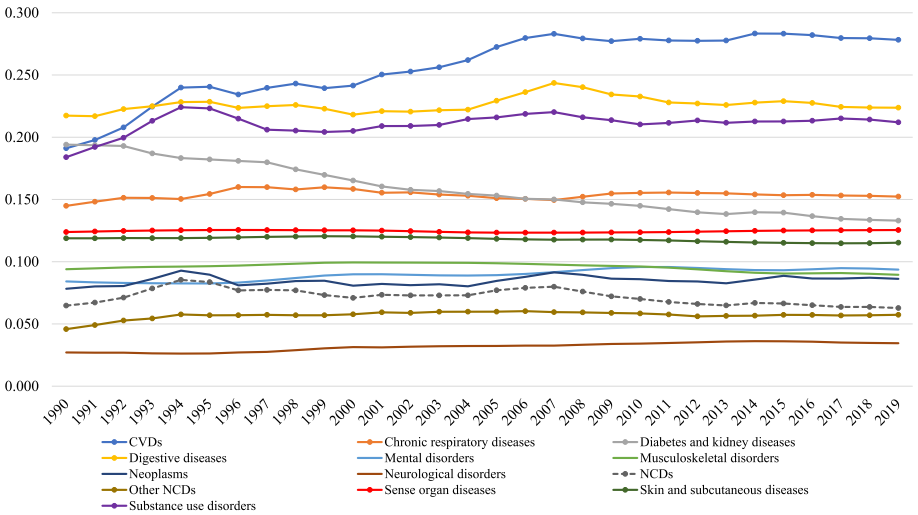

Fig. 5 Gini coefficient of age-standardized NCDs DALY rate in EEA Member States, 1990–2019. Legend: NCDs: non-communicable diseases and CVDs: cardiovascular diseases

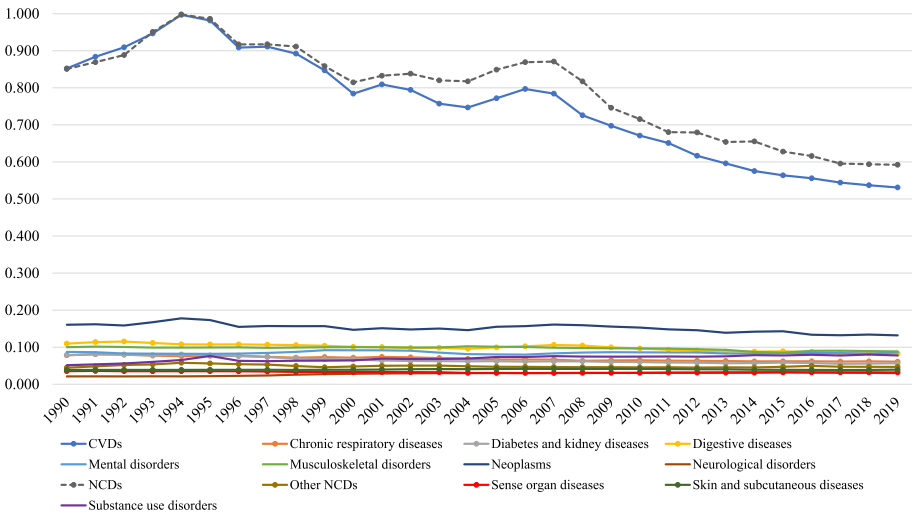

Fig. 6 Slope Index of Inequality of age-standardized NCDs DALY rate in EEA Member States, 1990–2019. Legend: NCDs: non-communicable diseases and CVDs: cardiovascular diseases

Discussion

This study describes DALY rates of NCDs as a snapshot in 2019, and their trends over three decades; and also presents DALY rate ratios, GC and SII to express health inequalities due to NCDs in EEA countries.

A progressive decrease in the age-standardized NCDs DALY rate for 30 EEA countries from 1990 to 2019 for both males and females was observed. Most countries remained similarly ranked compared to other countries over the years, showing a proportional decrease in DALYs in 2019 compared to 1990. Furthermore, the pace of decrease in DALY rate was similar across countries, the ratio of DALY rate across country-pairs remained similar, and the overall NCDs DALY rate decreased in the EEA region. Thus, despite a general improvement in the burden of disease across all countries from 1990 to 2019, and despite a narrowing of income inequalities between countries in the same period [59], the inequalities in the disease burden between the EEA countries has remained.

The progressive decrease of NCDs DALY rate in western european countries, such as Austria, Belgium, Denmark, and Iceland, were far more steady and lower during the follow up period. Whereas, for the EU-11 countries, which include Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania,

Slovenia and Slovakia, a different trend was observed. Bulgaria, Latvia, Lithuania, and Estonia showed a fluctuating DALY rate, with peaks in 1994 and 2007. The significant upsurge in the DALY rate within those countries, notably Bulgaria, during the period from 1990 to approximately 1997, is noteworthy, particularly with regard to the male population. Subsequently, these countries show a comparable level of reduction in the DALY rate as observed in other countries. However, they initiated their decrease trajectory from a markedly higher rate, which may indicate that those countries experienced events leading to the decrease of DALY rate for NCDs. The peak in 1994 may be explained by the socio-economic crisis following the dissolution of the Soviet Union and the collapse of the communist governments, as well as the transformation of the health systems, which was reflected in greater inequalities and an increase in the mortality rate from NCDs in the countries of the region [60]. In three Baltic countries—Latvia, Lithuania, and Estonia – the NCDs DALY rate increased dramatically in 1991, peaked in 1994 and then returned to a lower level in 1996. The increase in NCD DALY rates in Bulgaria, and others, for the period 1990 to 1997 reflects the economic crisis observed in the period, peaking with hyperinflation at the end of 1996 and the beginning of 1997. These factors suggest that post-socialist countries might have suffered an economic and political crisis, in which the impacts on health appeared at different times.

Another peak in NCDs DALY rate increase started in 2004, when Latvia, Lithuania, and Estonia joined the EU, which might be explained by cross-border migration of youth [61]. This trend peaked in 2007 and then started to fall back to a downward trend for NCDs—showing that the health status deteriorated after the enlargement of 2004 and 2007 for some new countries [62]. However, other studies have found no convincing evidence that EU accession has affected the process of mortality convergence between the pre-2004 and post-2004 Member States [61].

The Great Recession in 2008 had a significant impact on the healthcare system of many countries in the EEA [63]. Governments have responded to the economic crisis by implementing financial austerity measures such as curbing healthcare spending and access to services. Widening health inequalities in the EU-27 were a major consequence of the Great Recession [64]. The economic crisis has also led to a decline in the quality of life and an increase in unemployment, as well as an increase in poverty, anxiety, suicide, alcoholism and malnutrition [63, 65]. All these adverse changes in socio-economic factors might had influenced the epidemiological and economic burden of NCDs [66].

However, establishing a direct temporal link between adverse socioeconomic changes as determinants and changes in DALYs in a given year can be very inaccurate, as most NCDs have a long latency period [67]. Moreover, differences between countries in physical inactivity and obesity may have led to greater inequalities in NCDs in Europe, as these two risk factors appear to have increased between 2004 and 2015, but some of these risk factors may take decades to have an impact on the YLL rates for most NCDs [68, 69]. Health inequalities between countries are influenced by many factors, beyond those listed above, such as differences between countries in the number of doctors and nurses per 100,000 people, in health expenditure, in national health promotion measures [70–72].

For some NCDs at level 2, the NCD DALY rate ratios were extremely high when a country with the highest DALY rate was compared with the lowest ranking country. The ratios for digestive diseases, diabetes and kidney diseases, substance use disorders, CVDs, and chronic respiratory diseases ranged from 2.73 (diabetes and kidney diseases in 2019) to 6.29 (digestive diseases in 1996). The GC coefficient confirms that the inequalities between all included countries are higher for these diseases in comparison to the others. This may draw attention to the need for targeted, disease-specific prevention programs in the EU. Most of these diseases are associated with an unhealthy lifestyle, distinguished by poor dietary patterns, harmful alcohol intake, and tobacco use. Nonetheless, these risk factors can be modified by means of lifestyle adjustments. Consequently, it is crucial for countries that demonstrate elevated DALY rates to intensify their preventive measures against these risk factors. For instance, Japan has one of the lowest NCD DALY rate in the world, and the country has very stablished and comprehensive public health policies, including active lifestyle promotion, healthy eating initiatives, and strict tobacco control measures [73, 74]. It is important to note that according to the SII analysis, the significant enhancement in the health-related to NCDs in EEA countries during the last three decades, is primarily attributed to the contribution of CVDs in absolute terms.

The observed decrease in health inequalities for diabetes and kidney disease is present in both analyses: pairs of countries (ratio) and all countries together (GC). In contrast, CVD exhibits an increase in both health inequalities analysis, which can be attributed to some countries having achieved significant improvements in CVD-related DALY values due to successful prevention and treatment measures, while others have experienced limited success, leading to a modest decline or stabilization in their DALY trends. The reduction in mortality from CVD can be attributed to advancements in prevention and treatment

approaches, as well as favorable changes in risk factors such as smoking, blood pressure, and cholesterol levels [75]. The contrasting trends between diabetes, kidney disease and CVD may also be due to differences in the weight of risk factors associated with each NCD. The major risk factors for diabetes and kidney disease include physical inactivity and obesity. The efforts made in these areas in Europe over the past three decades have disappointingly failed [76], and on a global scale, there is not much success to report. Although the burden of CVD has declined more than that of diabetes in Europe during this period [77], both diseases persist as significant public health challenges necessitating effective prevention and treatment strategies [76, 78].

According to WHO Global NCD Action Plan 2013–2030, the recommended interventions are to reduce the risk factors for NCDs (tobacco use, harmful use of alcohol, unhealthy diets, physical inactivity) and to enable health systems to respond to the health needs of people living with or at risk of the major NCDs (cardiovascular diseases, cancers, diabetes, chronic respiratory diseases). Among prevention policies, only tobacco control has seen systematic international action. In addition to the WHO Framework Convention on Tobacco Control (FCTC), which entered into force in 2005, the EU legislative framework for tobacco control has been developed. The instruments of the legal framework include marketing rules, educational campaigns, pharmacotherapy and tobacco taxation policy. Smokers are more prevalent in countries with low levels of tobacco control enforcement [79]. In the EU-27, Member States that implement more measures to reduce smoking prevalence and encourage smoking cessation report more people quitting and lower rates of smoking [80].

However, there are no enforceable international/EU treaties or other legal instruments for the control of other behavioral risk factors. For example, international efforts to regulate alcohol consumption have been less successful than in the case of tobacco [81]. Moreover, the effectiveness of policies to prevent or reduce harmful alcohol consumption has not been adequately assessed yet [82, 83]. In the EU, some fragmented interventions and policies are mainly based on implementing control over alcohol availability, pricing policies, educational interventions, screening risk drinkers, and brief intervention [84–86].

Policies can contribute to reducing health inequalities and creating the conditions for a healthy life for all. The WHO Health Equity Policy Tool (2019) connects five essential conditions for a healthy life (health services, income security and social protection, living conditions, social and human capital, and employment and working conditions) to policy areas for which evidence for action is strong. To reduce inequalities in NCDs, a network of policies is needed, including environmental measures (housing, transport) and measures to address commercial determinants of health (marketing, taxing unhealthy products, and promoting fruit and vegetable production, removal of unhealthy products rich in sugar, salt and fat from automatic vending machines, especially in school and work premises). Policies should be focused on detecting, monitoring, and preventing physiological and behavioral factors for NCDs, with a specific focus in lower socioeconomic classes [87].

In European countries, sex inequalities in health are apparent. Disparities in DALY were greater for males than for females, in all the absolute and relative analyses we conducted. However, as depicted in the maps, the annual rate of change between 1990 and 2019 was much lower for males, implying that the DALY rate for NCDs have declined substantially over the 30-year period.

The high equality level in the DALY rate ratio of the female population can be explained by both countries having similar DALY rate. However, this does not necessarily reflect low DALY rate, since the compared countries can present similarly high rates and thus the ratio will be close to 1, demonstrating that there is a ceiling effect in the ratio calculation that may mask variation. Also, NCDs YLL rates for males are much higher than the YLL for females. In opposite, YLD rates for females was higher than YLD for males. This inverse association of higher YLL rates for males and higher YLD rates for female is probably related to differences in lifestyle choices, risk behavior and access to healthcare [88]. In Europe, males are more prone to adopt unhealthy behavior (excessive alcohol and tobacco consumption) and hazardous jobs (exposure of harmful substances and dangerous workspaces) [89, 90]. In addition, as females are more aware of their health status and have access to preventive health services, they attend more screening programs and seek health care when they have symptoms of NCDs, leading to higher life expectancy [88]. It could also be assumed that the observed trends in DALY rate from 1990 to 2019 for all NCDs were primarily determined by YLL rates and that YLD rates contributed less.

As compared to previous studies on health inequalities in Europe, the main strengths of this study are longer follow-up period, better data availability, use of age-standardization measures, and inclusion of all EEA countries [50, 88, 91]. The use of age-standardization of DALY rate elicited from the GBD study allows a harmonized and validated measure of both NCD mortality and disability. Additionally, the use of age-standardized rates allowed us to compare data between many countries, across 30 years of follow up, with different economic backgrounds and age profiles. We also aimed to diminish bias by calculating inequality not only using ratios,

but also the SII and GC, which provide both an absolute and relative depiction of inequality. Also, analyzing inequalities at level 2 NCDs provided unique results regarding the differences in inequalities in each disease group. As this is an important variable in terms of political and economic resources, it was also appropriate to compare sex inequalities. The objective underlying the provision of detailed tables and graphs in this study was to facilitate the analysis and comprehension of health inequalities between countries and within the EEA. Through the inclusion of highly comprehensive tables and graphs, we achieved our aim of providing a broad understanding of the ratios, not solely pertaining to the comparison between the country exhibiting the highest and lowest DALY rates, but also encompassing any pair of countries examined in our sample. Moreover, the meticulous information concerning the analysis of international disparities includes not only comparisons between individual country pairs but also encompasses the entire sample of countries included in the research.

The present study has some limitations, many of them are intrinsic limitations of the GBD study—these can be found elsewhere [47]. The uncertainty of estimates due to limited data, possibility of inaccurate determination and classification of non-fatal conditions, and lack of primary data (particularly for morbidity data). However, a few limitations are unique to our study. One of them is the determination of inequality according to DALY rate over a 30-year period, which included the ratio only between extremes: highest ranking country/lowest ranking country. However, the GC, SII, and the contingency table were included to mitigate this limitation by including all the countries and/or all the years in the analysis. The method of employing statistical significance analysis as the overlapping 95% UI demonstrates effectiveness in detecting statistical significance whereby non-overlapping intervals indicate significance. However, this approach may not consistently provide reliable outcomes in the opposite direction, when slightly overlapping 95% UI may still yield statistical significance. Despite this limitation, the employment of the 95% UI remains preferable over the 95% CI since it incorporates model uncertainty, thus rendering it a more meaningful measure. Moreover, relying on Poisson regression to produce p-values and 95% CIs would indicate statistical significance for almost all ratios, given its exclusive focus on DALY rates. In contrast, the adoption of the 95% UI overlapping rule is a more significant measure, particularly as the GBD 2019 study incorporates various other epidemiological metrics into its calculation of UI. The GBD database does not present estimates for microstate Liechtenstein, which was the only country excluded from our analysis of EEA member states. An additional limitation is the assumption of linear change in the annual change estimates, since our analysis showed that, for some former Soviet countries, this assumption might be incorrect. However, this was mitigated by depicting the DALY rate of change over each year for each country visually. The data quality is, furthermore, diverse. Depending on the country, the GBD uses Bayesian methods to try and overcome this. Non-fatal data can differ dramatically between countries; for this reason, the Bayesian models may lead to incorrect estimates based on the surrounding countries. Also, inequalities exist both within and between countries, but the present study only compared inequalities between countries.

Conclusions

In conclusion, our study shows that the NCDs with higher level of inequality across countries of EEA are digestive diseases, diabetes and kidney diseases, substance use disorders, CVDs, and chronic respiratory diseases. However, the GC analysis showed that the level 1 NCDs DALYs inequality within all included countries is narrow. This study also highlighted that the DALY rate from NCDs decreased between 1990 and 2019 in all the 30 EEA member states. The rate of change, however, varied between males and females and across regions and was larger for males and in Central European countries. Underlying social inequalities could be reduced through the right selection of policies. In addition to policies that target modifiable risk factors, emphasis should also be placed on health inequalities between EEA Member States that may also be due to the heterogeneity of social factors.

Abbreviations

CVDs	Cardiovascular diseases
DALYs	Disability-adjusted Life Years
DM	Diabetes Mellitus
EEA	European Economic Area
EU	European Union
GBD	Global Burden of Disease
GC	Gini Coefficient
GDP	Gross Domestic Product
NCDs	Non-communicable Diseases
SDG	Sustainable Development Goal
SII	Slope Index of Inequality
UI	Uncertainty Interval
UK	United Kingdom
UN	United Nations
WHO	World Health Organization
YLD	Years Lived with Disability
YLL	Years of Life Lost

Supplementary Information

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Additional file 1: Figure: Age-standardized NCDs YLLs and YLDs rate for EEA Member States by sex, 1990–2019. Legend: UI 95% for the overall highest (Bulgaria) and lowest (Iceland) DALYs rate are shown in grey and blue shaded band, respectively.

Additional file 2: For females, the UK had the highest annual rate of change, followed by Estonia and Finland. The countries with the lowest annual rates of change for females were Cyprus, Romania and Italy. In the EEA, the lowest annual rate of change for females was reported for CVDs at -0.54, followed by DDs at -0.26 and CRDs at -0.16. For males, the highest annual rates of change in DALYs were in Estonia, followed by the UK, and the lowest in Italy, Spain and Portugal. For males in the EEA, the lowest annual disease-specific rate of change was -0.55 for CVDs, followed by CRDs -0.39 and then DDs -0.32. Figure: Age-standardized level 2 NCDs DALY annual rate of change by EEA Member States, 1990–2019. Legend: CVDs: cardiovascular diseases.

Additional file 3: Figure: Slope Index of Inequality of age-standardized level 1 and 2 NCDs DALYs rates, 1990–2019. Legend: CVDs: cardiovascular diseases; CI: Confidence Interval; NCDs: non-communicable diseases; Coef.: Coefficient.

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Authors' contributions
CASA, EL, JAH, and OV conceptualized the study. CASA, NM, PC, CMB, EL, JAH, and OV assisted and created the methodology. CASA, NM, and CMB worked on the statistical analysis. CASA and OV prepared and wrote the original draft. CASA, NM, JG, PC, SC, DAG, BU, EAM, JCX, BD, GI, EL, CMB, FF, NW, MB, RH, ME, JAH, and OV cooperated on the research visualization. EL, JAH, and OV supervised the research. BD and OV were the project administrators. All authors wrote, reviewed, and edited the main manuscript.

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Availability of data and materials
Data are available in a public, open access repository (ghdx.healthdata.org). The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Public Health and Epidemiology, Faculty of Medicine, University of Debrecen, 26 Kassai Street, 4028 Debrecen, Hungary. [2]Faculty of Medicine, University of Basel, Basel, Switzerland. [3]Department of Public Health, Erasmus MC University Medical Center, Rotterdam, The Netherlands. [4]Faculty of Medicine and Surgery, University of Malta, Msida, Malta. [5]Department of Public Health, Babes-Bolyai University, Cluj-Napoca-Napoca, Romania. [6]RoNeuro Institute for Neurological Research and Diagnostic, Cluj-Napoca-Napoca, Romania. [7]Department of Cardiovascular, Endocrine-Metabolic Diseases and Aging, Istituto Superiore Di Sanità, Rome, Italy. [8]Department of Healthcare, Faculty of Health, University of Vlora, Vlora, Albania. [9]Clinic of Social and Family Medicine, School of Medicine, University of Crete, Crete, Greece. [10]Public Health Unit, Primary Healthcare Cluster Baixo Mondego, Coimbra, Portugal. [11]National School of Public Health, NOVA University of Lisbon, Lisbon, Portugal. [12]Department of Epidemiology and Public Health, Sciensano, Brussels, Belgium. [13]Department of Translational Physiology, Infectiology and Public Health, Ghent University, Merelbeke, Belgium. [14]Department of General Surgery and Surgical Medical Specialties, University of Catania, Catania, Italy. [15]Department of Epidemiology and Health Monitoring, Robert Koch Institute, Berlin, Germany. [16]Department of Disease Burden, Norwegian Institute of Public Health, Bergen, Norway. [17]Institute of Public Health, Charité - Universitätsmedizin Berlin, Berlin, Germany. [18]Department of Clinical Epidemiology, Aarhus University and Aarhus University Hospital, Aarhus, Denmark. [19]Department of Sociology and Political Science, Centre for Global Health Inequalities Research (CHAIN), Norwegian University of Science and Technology (NTNU), Trondheim, Norway. [20]Department of Non-Communicable Diseases and Injuries, Santé Publique France, Saint-Maurice, France. [21]Department of Nursing, School of Health Sciences, Cyprus University of Technology, Limassol, Cyprus.

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Publisher's Note

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Differential age-associated brain atrophy and white matter changes among homeless and precariously housed individuals compared with the general population

Jacob L Stubbs,[1,2] Andrea A Jones,[3] Daniel Wolfman,[1,2] Ryan C Y Chan,[1,2] Fidel Vila-Rodriguez,[1,4] Alexandra T Vertinsky,[5] Manraj K Heran,[5] Wayne Su,[1,2] Donna J Lang,[2,5] Thalia S Field,[3] Kristina M Gicas,[6] Melissa L Woodward,[1,2] Allen E Thornton,[2,7] Alasdair M Barr,[8] Olga Leonova,[1] William MacEwan,[1] Alexander Rauscher,[9] William G Honer,[1,2] William J Panenka[1,2,10]

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For numbered affiliations see end of article.

Correspondence to
Jacob L Stubbs;
stubbs.jacobliam@gmail.com

ABSTRACT

Background Homeless or precariously housed individuals live with poor health and experience premature mortality compared with the general population, yet little is known about age-related brain changes among these individuals. We evaluated whether MRI measures of brain structure are differentially associated with age and selected risk factors among individuals who are homeless or precariously housed compared with a general population sample.

Methods We compared T1-weighted and diffusion tensor imaging measures of brain macrostructure and white matter microstructure in a well-characterised sample of 312 precariously housed participants with a publicly available dataset of 382 participants recruited from the general population. We used piecewise and multiple linear regression to examine differential associations between MRI measures and between the samples, and to explore associations with risk factors in the precariously housed sample.

Results Compared with the general population sample, older age in the precariously housed sample was associated with more whole-brain atrophy ($\beta=-0.20$, $p=0.0029$), lower whole-brain fractional anisotropy ($\beta=-0.32$, $p<0.0001$) and higher whole-brain mean diffusivity ($\beta=0.69$, $p<0.0001$). Several MRI measures had non-linear associations with age, with further adverse changes after age 35–40 in the precariously housed sample. History of traumatic brain injury, stimulant dependence and heroin dependence was associated with more atrophy or alterations in white matter diffusivity in the precariously housed sample.

Conclusions Older age is associated with adverse MRI measures of brain structure among homeless and precariously housed individuals compared with the general population. Education, improvements in care provision and policy may help to reduce the health disparities experienced by these individuals.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Individuals who are homeless or precariously housed have a higher burden of illness as compared with the general population.

WHAT THIS STUDY ADDS

⇒ This is the first study to look at differential associations between quantitative MRI measures of brain health and age among these individuals compared with the general population. In this cross-sectional analysis of 694 participants, we found that older age was more strongly associated with adverse MRI measures of brain structure among those who were precariously housed compared with the general population.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Care providers should be aware of the differences in brain health and consider earlier evaluation and intervention, with traumatic brain injury and substance dependence being especially important brain health factors to consider. Policy-makers should consider increasing targeted availability and/or expanded eligibility of supportive services.

INTRODUCTION

Individuals who are homeless experience disproportionately high morbidity and mortality compared with the general population,[1] and individuals who are precariously housed face similar mortality as those who are homeless.[2] Previous studies report considerably higher rates of communicable diseases,[3] mental illness[4] and substance misuse, as well as high rates of unintentional injury such as falls, assault and traumatic brain injury.[5 6] Previous studies also report higher rates of

non-communicable diseases, cognitive impairment and age-related conditions, which some have taken as evidence for accelerated ageing.[5] Indeed, homeless individuals over the age of 50 have a high prevalence of 'geriatric syndromes', comparable with general population samples more than 20 years older.[7 8]

There is preliminary evidence for differential brain changes in homeless and precariously housed samples, with a higher-than-expected prevalence of stroke and nearly one-third having pathological findings visible on MRI.[9 10] Only one study to date has looked at quantitative MRI in homeless individuals compared with a control group and found that homeless individuals had smaller thalamic and brainstem volumes compared with controls, and that history of traumatic brain injury was associated with lower volumes of various brain structures compared with those without traumatic brain injury.[11] However, this study was limited in sample size ($n_{homeless}$=25, $n_{control}$=26) and reported only basic between-group differences in volume across a few regions of interest. To date, it is unknown whether MRI measures of brain structure differ between homeless or precariously housed individuals compared with the general population, or whether there is a differential association with age that could indicate accelerated degenerative processes. If there are differential associations between MRI measures of brain structure and age, there are potential implications for education, public health policy and health delivery, especially given the ageing homeless population.[12]

In this study, we evaluated whether age is differentially associated with MRI measures of brain structure in a well characterised sample of individuals who are precariously housed (n=312) compared with a publicly available sample of individuals from the general population (n=382). We hypothesised that older age would be associated with greater whole-brain atrophy and differential white matter diffusivity among precariously housed individuals compared with the general population. We characterised differential associations with age across regions of interest and also explored whether risk factors that are over-represented in homeless or precariously housed samples, such as mental illness diagnoses, substance dependence, intravenous drug use, HIV, traumatic brain injury or stroke, were associated with atrophy or white matter diffusivity in the precariously housed sample.

METHODS

Study samples and participants

The Hotel Study is a prospective longitudinal observational study of individuals who are precariously housed in an impoverished neighbourhood of Vancouver, Canada.[10 13 14] Participants were recruited from single-room occupancy hotels, a downtown community court and a local hospital emergency department and were assessed monthly and yearly on various aspects of health and functioning, including one or more multimodal MRI scans of the brain. Inclusion criteria included being aged 18 or older, ability to speak English and ability to provide informed consent; no other exclusion criteria were applied. Participants in this study are demographically similar to studies on homelessness and have comparable health characteristics.[15 16] Mental illness and substance use diagnoses were assessed using the best estimate clinical evaluation and diagnosis form by study psychiatrists,[17] HIV status by baseline serology and traumatic brain injury was operationalised as being struck in the head, neck or face, and losing consciousness for any period of time, as assessed through a structured interview. MRI scans were acquired for research purposes and not for any specific clinical indication. Any clinically significant incidental findings were reported to the participants and their care providers. Of the 515 participants enrolled in the broader study, we included baseline data from participants between the ages of 18 and 65 who had a T1-weighted and diffusion tensor imaging (DTI) scan of sufficient quality to be analysed (n=312). Age 65 was selected as an upper bound as it aligns with the Canadian Government (and commonly used) cut-off between adulthood and older adulthood.[18]

Data from the general population was collected as part of the population-based and open-access Cambridge Centre for Ageing and Neuroscience repository (CamCAN; http://www.mrc-cbu.cam.ac.uk/datasets/camcan/).[19 20] The CamCAN dataset was selected as it is a comparably large dataset with all imaging acquired on a single MRI scanner. To facilitate comparison to the Hotel Study sample, we included participants who were between the age of 18 and 65 who had a T1-weighted and DTI scan of sufficient quality to be analysed (n=382). In supplementary analyses, we also evaluated an additional healthy control sample that was acquired on the same scanner, with the same acquisition parameters as the Hotel Study sample (n=35), and processed identically to Hotel Study scans. These additional scans were acquired as part of a control sample for a different study and thus, there was no blinding of participant group required for research staff.

Neuroimaging acquisition and processing

For the Hotel Study sample, T1-weighted and diffusion tensor imaging scans were acquired on a 3T Philips Achieva scanner with an eight-channel SENSE head coil and for the CamCAN sample all scans were acquired on a 3T Siemens TIM Trio scanner with a 32-channel head coil. Scan acquisition parameters are detailed in the online supplemental methods.

All scans were processed using similar processing pipelines. T1-weighted scans were processed using FreeSurfer V.6.0[21] with full processing and quality control details outlined in the online supplemental methods. Tissue-to-intracranial volume ratio was derived by dividing total cerebral brain tissue volume (excluding the ventricles, cerebellum and brainstem) by estimated intracranial volume. Cortical thickness was extracted according to the Desikan-Killiany atlas[22] and subcortical volumes were

extracted according to the standard FreeSurfer subcortical segmentation atlas.[23] Hotel Study DTI scans were processed using FSL V.5.0.11 and CamCAN DTI scans were processed with FSL V.6.0 (https://fsl.fmrib.ox.ac.uk),[24] with full processing and quality control details outlined in the online supplemental methods. Mean whole-brain fractional anisotropy (FA) and mean diffusivity (MD) data were extracted by taking an average from the white matter skeleton, and values across white matter tract regions of interest were exported according to the Johns Hopkins University white matter tract atlas.[25] In general, decreased FA and increased MD is indicative of damaged or degraded white matter integrity, and this pattern is generally seen with increasing age.[26] However, DTI findings are not specific to any particular pathology and can change throughout a disease process, and thus, conservative interpretation about the exact meaning of DTI measures is required.[26] Therefore, we constrain our interpretation of our DTI findings to 'alterations in diffusivity' rather than making any direct interpretations about the underlying brain pathology.

Statistical analysis

We tested for differences between samples in median age with a Wilcoxon rank-sum test, and for differences in the proportion of sex between samples with a χ^2 test. We centred all MRI measures in each sample to the sample mean (ie, CamCAN values were centred on the CamCAN sample mean for that metric) and standardised the data. We report standardised beta weights throughout to facilitate comparison across imaging metrics and samples. We first looked at broad, whole-brain measures including tissue-to-intracranial volume ratio, cerebral white matter volume, cortical volume, subcortical grey matter volume, average whole-brain FA and average whole-brain MD. We describe the difference in average slope between age and these whole-brain measures using multiple linear regression with a sample×age interaction term. However, there were non-linear associations between age and several whole-brain measures. Quadratic terms improperly describe non-linear relationships in cross-sectional studies[27] and other non-linear methods (eg, general additive models) yield coefficients that are challenging to interpret and compare across measures or samples. Therefore, we used piecewise regression to algorithmically estimate the age at which the breakpoints occurred and estimate slopes before and after the breakpoint.[28] We also evaluated differential associations between age and cortical thickness, subcortical volumes and white matter diffusivity across regions of interest using multiple linear regression with sample×age interaction terms. As shown in online supplemental figure 1, linear approaches provided good estimates of average slope across the lifespan compared with non-linear approaches, so we used linear models to characterise region of interest results with one single standardised value for each region of interest. As shown in online supplemental figure 2, the slope for whole-brain atrophy in the CamCAN sample was not significantly different from the healthy control sample acquired on the same scanner as the Hotel Study sample. Therefore, we use the CamCAN sample as the primary comparator throughout due to the larger sample size. We covaried for estimated intracranial volume for all volumetric measures except for tissue-to-intracranial volume ratio and we covaried for sex for all measures. All region of interest analyses were corrected for multiple comparisons to a false discovery rate of $p<0.05$.

One major factor that could disproportionately influence our results are individuals who had structural lesions due to traumatic brain injury, a subgroup which is over-represented in the precariously housed sample compared with the general population.[29] To evaluate whether our results were largely driven by these individuals, we first created a lesion overlap figure to describe the distribution and overlap of the lesions. We manually drew the lesion mask for each participant in FSL using T1-weighted and FLAIR images that were coregistered and then non-linearly registered the T1-weighted images and lesion masks to the MNI-152 standard space. To run the sensitivity analysis, we removed these participants and ran identical models to our original analyses. A second subgroup that could potentially influence our results are individuals who had MRI evidence of stroke. This has been characterised previously in detail in a largely overlapping sample of participants, but in general the strokes were relatively small and either lacunar or cortical.[9] As the strokes were generally small, we did not create a lesion overlap figure but we did re-run our analyses with these participants removed.

Finally, we explored whether factors such as mental illness diagnoses, substance dependence, intravenous drug use, HIV positivity, traumatic brain injury or stroke were associated with tissue-to-intracranial volume ratio or mean whole-brain FA in the precariously housed sample. To account for missing data, we used multiple imputation as described in the online supplemental methods. We used multiple linear regression with an age^2 term to account for the non-linear relationships of the imaging variables with age, and then successively added blocks of variables.

All statistical analyses were conducted in R V.4.0.4,[30] with piecewise regression implemented using the segmented package,[31] region of interest results displayed using the ggseg package[32] and multiple imputation performed using the mice package.[33]

RESULTS

The total sample included 694 participants, with 382 from the general population (CamCAN) sample and 312 from the precariously housed (Hotel Study) sample. The general population sample was slightly older (44.2 vs 41.8; W=67 022, p=0.0047) and had a lower proportion of males (47.6% vs 78.8%; χ^2=69.4, p<0.0001), and all subsequent analyses were adjusted for age and sex.

The crude relationships between whole-brain imaging outcomes and age for each sample are shown in figure 1, with adjusted estimates reported in-text and in online supplemental table 1. Older age was associated with whole-brain atrophy in both samples; however, the precariously housed sample had a stronger association than the general population (β=−0.20, p=0.0029). The relationship between atrophy and age was linear in the general population and non-linear in the precariously housed sample, where older age was associated with more atrophy after age 37.0 (95% CI=30.0 to 44.0). The association between age and atrophy was 6.5 times the slope before age 37 and approximately two times the magnitude of association as in the general population.

The differential atrophy in the precariously housed sample appeared to be largely driven by cerebral white matter volume (β=−0.12, p=0.0015), as neither cortical volume (β=−0.049, p=0.16) nor subcortical grey matter volume (β=−0.060, p=0.19) were significantly different in slope compared with the general population, and both declined linearly in each sample. The relationship between age and cerebral white matter volume was linear in the general population and stable across the age range. In contrast, the relationship was non-linear in the precariously housed sample as older age was associated with higher cerebral white matter volume up to age 39.8, after which it was associated with lower cerebral white matter volume.

There was also a stronger association between age and both whole-brain FA (β=−0.32, p<0.0001) and whole-brain MD (β=0.69, p<0.0001) in the precariously housed sample relative to the general population, with non-linear relationships in both samples for each metric. After age 36.4 in the precariously housed sample, older age was associated with lower FA at a magnitude 5.7 times that of the association before the breakpoint and approximately two times that of the general population at a similar age. After age 43.4 in the precariously housed sample, older age was associated with higher MD at a magnitude 5.4 times that of the association before the breakpoint and 7.9 times that of the general population at a similar age.

Differential associations with age for cortical thickness, subcortical volumes and white matter tract diffusivity between the two samples is shown in figure 2, with full results reported in online supplemental table 2–4. In the precariously housed sample compared with the general population, older age was associated with lower cortical thickness in the middle and inferior temporal areas bilaterally, temporal poles and the middle frontal and medial orbitofrontal areas, lower corpus callosum volume, higher third and lateral ventricle volumes, lower FA in 16 of 20 tracts and higher MD in 14 of 20 tracts.

Overall, 19 of the 312 precariously housed participants (6.1%) had MRI evidence of encephalomalacia attributable to traumatic brain injury, figure 3. Traumatic brain injury lesions most commonly affected the frontal and orbitofrontal regions, as well as the temporal poles, consistent with the known vulnerability of these regions to trauma.[34] Additionally, 17 (5.4%) of the precariously housed participants had MRI evidence of stroke, which has been characterised in detail previously.[9] There were no substantive changes in the nature or direction of our findings with either of these subgroups removed (online supplemental table 5 and online supplemental figures 3–5), indicating that our results are not unduly driven by individuals with MRI evidence of traumatic brain injury or stroke.

Finally, we explored whether factors such as mental illness diagnoses, substance use, intravenous drug use, HIV, history of traumatic brain injury or MRI evidence of stroke were associated with atrophy or whole-brain FA in the precariously housed sample. The final blocks showing all risk factors we explored are shown in figure 4 and the preliminary models and full results are reported in online supplemental tables 6 and 7. Male sex (β=−0.47, p=0.00049) and history of traumatic brain injury (β=−0.35, p=0.0017) were independently associated with greater atrophy. Heroin dependence was associated with lower FA (β=−0.28, p=0.031) and stimulant dependence was associated with higher FA (β=0.34, p=0.034). MRI evidence of stroke fell just outside of statistical significance for both tissue-to-intracranial volume ratio (−β=0.42, p=0.056) and mean whole-brain FA (β=−0.47, p=0.054).

DISCUSSION

In this study, we found that older age was associated with decreased MRI measures of brain structure among individuals who were homeless or precariously housed compared with the general population. We also found that male sex and history of traumatic brain injury were associated with more atrophy in the precariously housed sample, and that stimulant and heroin dependence were associated with altered white matter diffusivity.

The process of ageing is generally understood to be complex and involves progressive allostatic load leading to physiologic and functional decline.[35 36] The decline of MRI measures of brain structure is part of the normal course of ageing in the general population and there is an accelerated decline in senescence.[37–40] However, we show that homeless or precariously housed participants have an age-associated decline that occurs earlier and in greater magnitude of that seen in the general population. Our results most likely reflect the effects of both systemic factors (eg, lack of housing) and individual factors (eg, development of mental illness, bodily injury) that accumulate and interact across the lifespan. This accumulation may result in accelerated brain changes where MRI measures of brain structure decline earlier among homeless or precariously housed individuals, similar to the accelerated decline with senescence seen in older

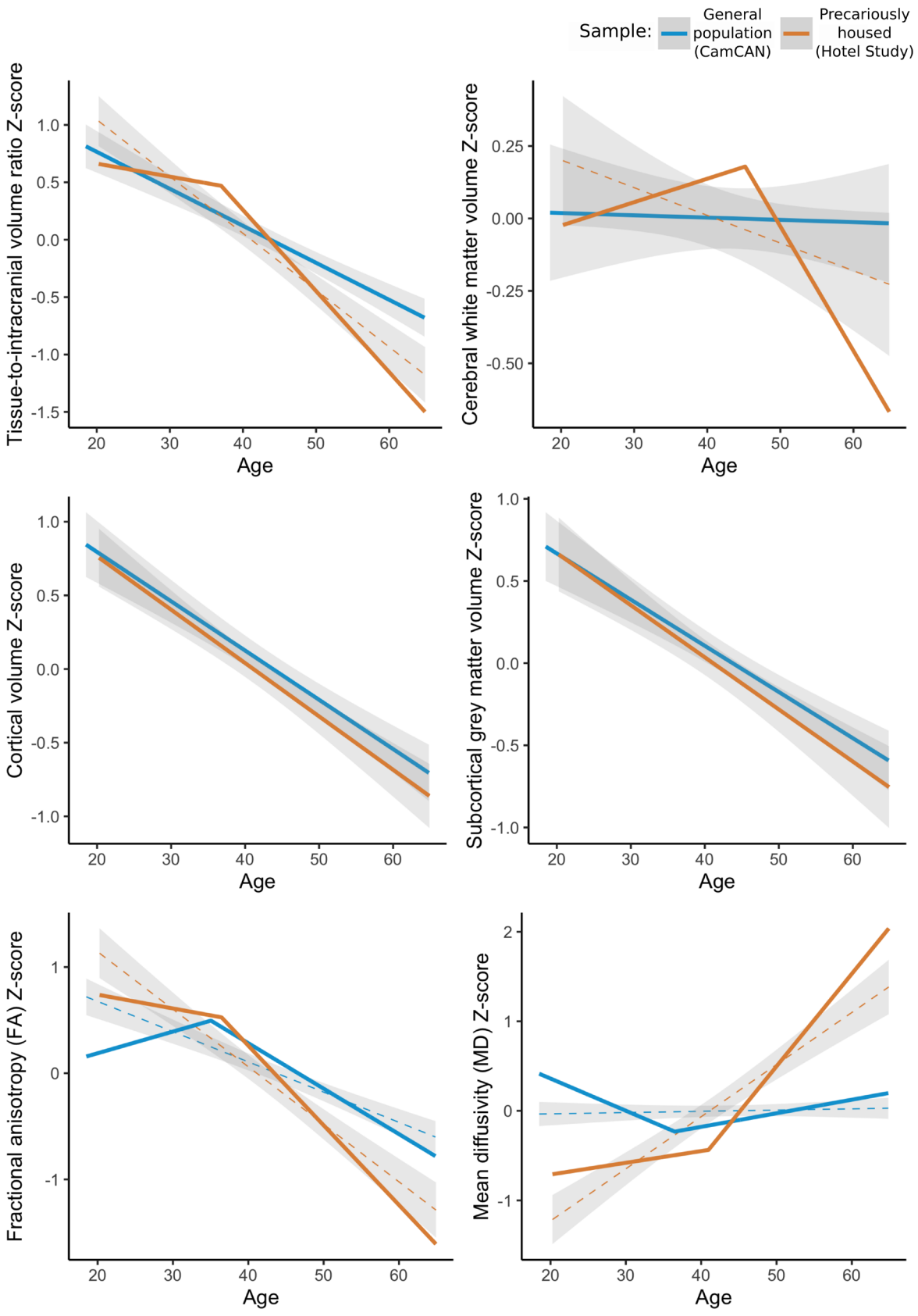

Figure 1 Whole-brain measures in the general population sample (Cambridge Centre for Ageing and Neuroscience (CamCAN); blue) and in the precariously housed sample (Hotel Study; orange). Each metric is centred to the mean of the respective sample and standardised. For linear relationships, a linear fit and shaded 95% CI is shown. For non-linear relationships, the piecewise regression estimates are shown with a dashed linear (+ 95% CI) fit shown for reference.

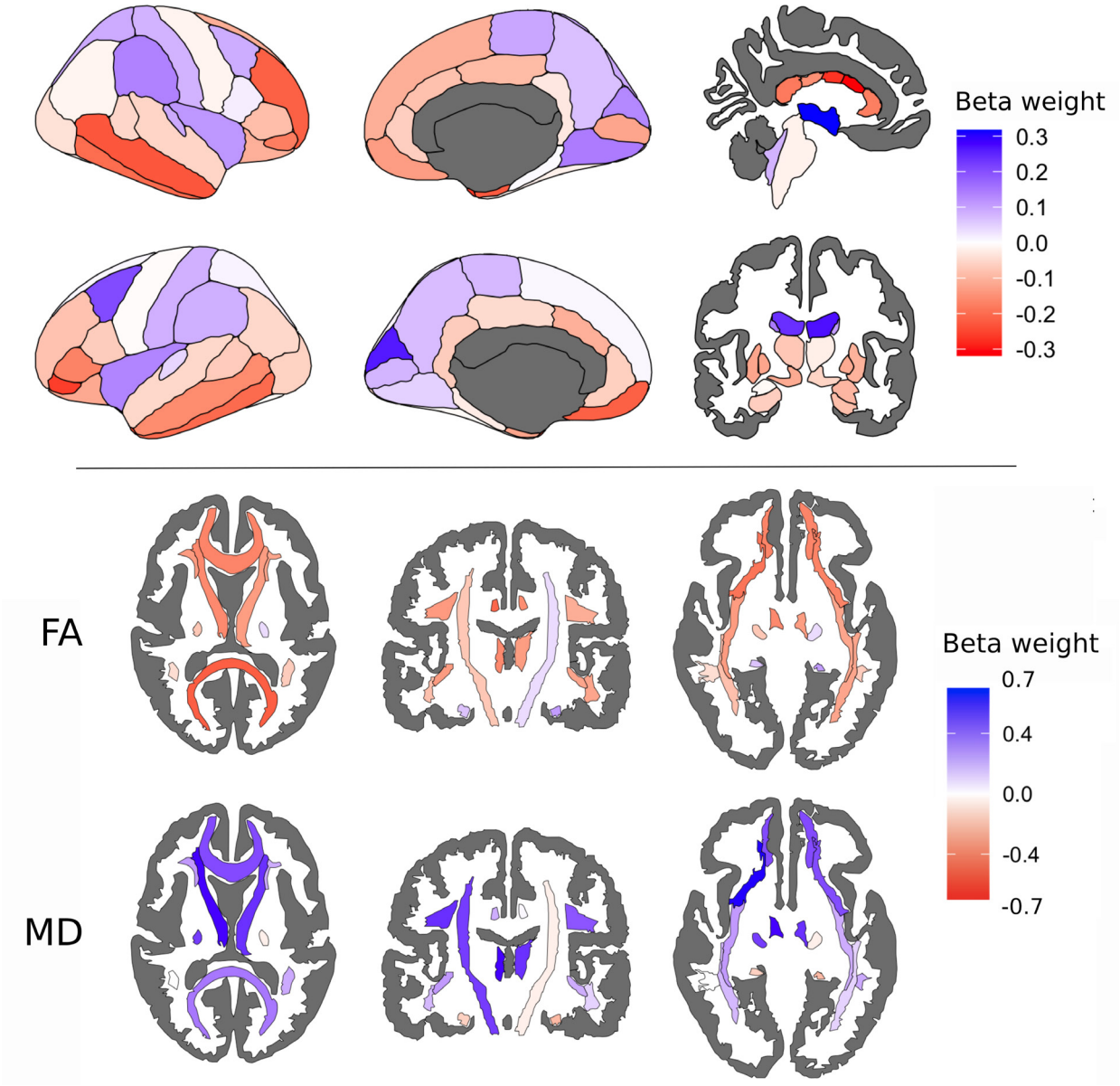

Figure 2 Differential associations across cortical, subcortical and white matter regions of interest between the general population and precariously housed sample. Beta weight is the standardised beta from a sample×age interaction term for each region in the Desikan-Killiany atlas (top panel, left), FreeSurfer subcortical atlas (top panel, right) and Johns Hopkins University white matter atlas (bottom panel). Positive (blue) beta weights indicate that the relationship between the imaging metric and age is more positive in the precariously housed sample compared with the general population and negative (red) beta weights indicate that the relationship between the imaging metric and age is more negative in the precariously housed sample compared with the general population. FA, fractional anisotropy; MD, mean diffusivity.

adults in the general population. This is supported by studies that have found a higher prevalence of other age-related conditions such as geriatric syndromes,[7 8] multimorbidity[10] and earlier mortality.[2]

Our results could also be partly due to the development of pathological conditions that are distinct from normal ageing. Brain atrophy, as assessed by structural neuroimaging, is a non-specific biomarker for conditions such as Alzheimer's disease[41 42] and cerebral small vessel disease.[43 44] Greater atrophy with age in our study may be indicative of a neurodegenerative process, especially among older participants. This is supported by previous research that has found that pathological conditions more often seen in older adults are also more common in this sample, with 46% having any neurological illness, 19% having a movement disorder and 11% with a history of stroke.[9 10]

History of traumatic brain injury was associated with additional atrophy in the precariously housed sample which is congruent with studies that have found a range of neuroimaging changes, including atrophy, in individuals from the general population after traumatic brain injury.[45 46] We also found that stimulant and heroin dependence were associated with altered

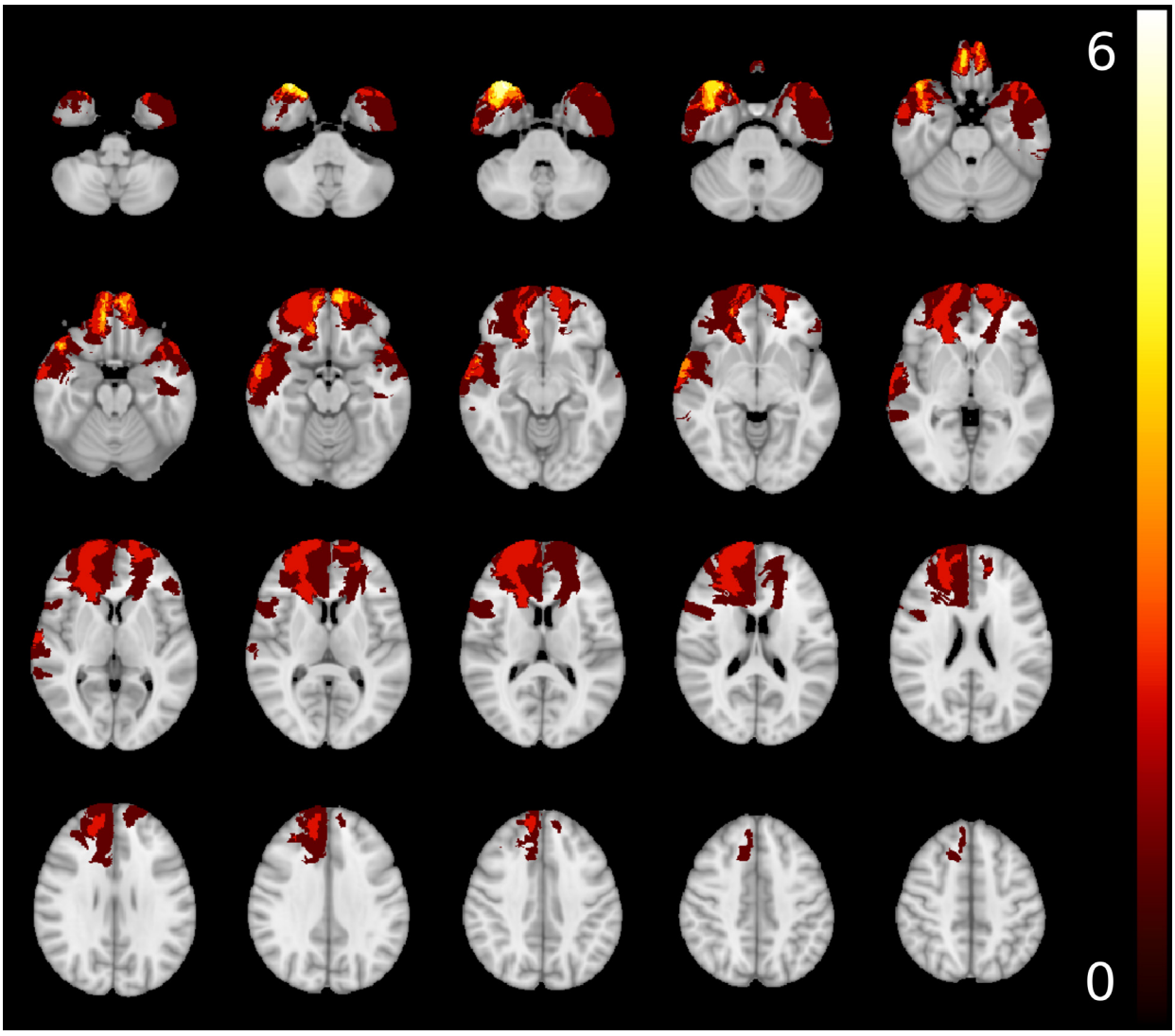

Figure 3 Overlap of lesions determined to be caused by traumatic brain injury in the precariously housed sample. Lesions are projected on the MNI-152 1 mm template. Yellow/white denotes higher number of lesions overlapping.

whole-brain white matter diffusivity. Previous studies report mixed findings and that the direction of the association between substance use and structural MRI measures depends on the specific substance and the region of interest.[47 48]

Our work has potential implications for care providers, policy-makers and researchers. First, care providers should be aware of this differential decline in MRI measures of brain structure and consider earlier evaluation and intervention for individuals experiencing homelessness or precarious housing. History of traumatic brain injury and substance dependence represent especially important factors to consider, and our work highlights the importance of accurate medical and injury history when working with vulnerable groups, especially given the association between traumatic brain injury and homelessness.[6 49] Second, our study contributes to the growing evidence showing a high burden of functional impairment, morbidity and mortality among these individuals. Policy-makers should consider increasing targeted service availability, or expanding service eligibility; for example, making supportive services targeted for seniors in the general population available to individuals in these groups at a younger age. Finally, future research should characterise predictors of longitudinal change in these groups and evaluate how changes in brain structure are associated with functioning. Age-related decline in cognitive function, for example, is associated with adverse changes in MRI measures of brain structure,[38] and thus, our results likely partially explain the well-documented cognitive and functional impairments experienced by these individuals.[50 51] Intervention studies specifically informed by the unique health challenges of this population (eg, earlier targeted cerebrovascular risk factor management strategies including non-traditional risk factors such as intravenous drug use[9] are also warranted in an effort to improve overall health.

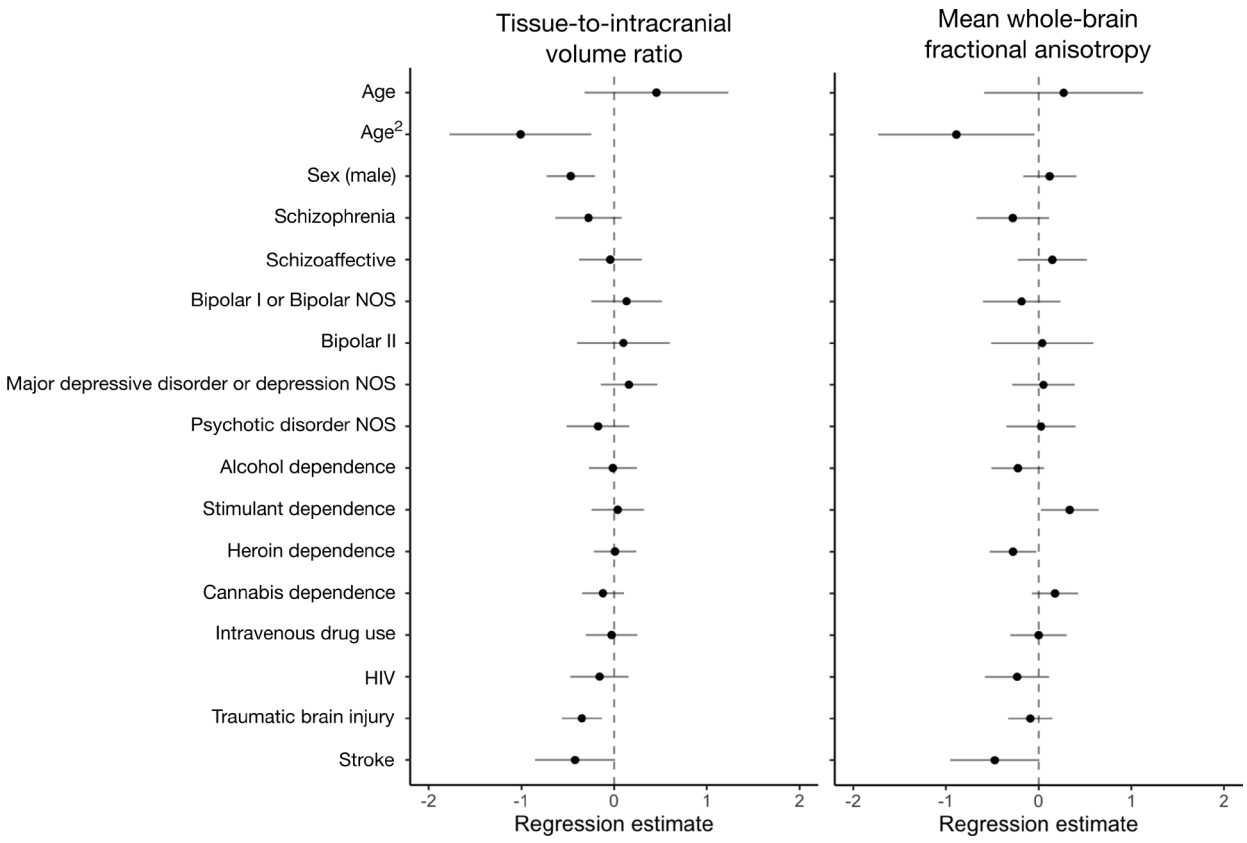

Figure 4 Forest plot of the associations between risk factors and tissue-to-intracranial volume (left) and risk factors and mean whole-brain fractional anisotropy (right). Error bars denote the 95% CI for the regression estimate. NOS, not otherwise specified.

Limitations

While our study leverages a well-characterised sample of precariously housed individuals and a large open-access sample from the general population, our work has several limitations. First, the two samples were acquired on different scanners with different acquisition parameters, and thus, comparison of the intercepts or 'main effects' could be biased by differences between scan acquisitions.[52] Therefore, we restricted our analyses to look only at the difference in slope between samples. Imaging metrics could be different in intercept but not slope in the precariously housed sample compared with the general population; however, future work with larger control samples acquired on the same scanner is needed to appropriately evaluate these relationships. Second, while quantitative MRI has been used extensively to evaluate brain structure in vivo, it is important to acknowledge that MRI measures of brain structure may be biased by a variety of factors and are not fully representative of the underlying biology.[53] Third, we used a cross-sectional approach to facilitate comparison to the general population. However, cross-sectional studies cannot evaluate what factors are associated with change over time, which may represent particularly important targets for intervention. Additionally, the Hotel Study and CamCAN samples were not rigorously matched on demographic or clinical variables, though we covaried for age and sex in all analyses. Rather, our aim was to use the CamCAN sample as a reference sample for what is normally expected in the general population and then to evaluate specific risk factors within the Hotel Study sample. There are also additional unmeasured variables (eg, acute illness) that could affect MRI measures of brain structure and introduce bias into our results. Future work with closely matched comparison samples will be able to further delineate the specific effects of risk factors on the brain structure of these individuals. Finally, we restricted our exploratory analyses on predictors of atrophy and FA to whole-brain measures. It is possible that some factors are associated with alterations in specific regions of interest but not with whole-brain measures. Additionally, co-use of substances is common, and our substance use variables were generated using a physician-assigned diagnosis of dependence (rather than any history of use). Future studies are needed to characterise the focal brain changes and dose–response characteristics associated with these risk factors.

CONCLUSIONS

Older age is associated with adverse MRI measures of brain structure among individuals who are homeless or

precariously housed well beyond the normal pattern seen in the general population. History of traumatic brain injury and substance dependence are factors that are over-represented among these individuals and associated with further atrophy and alterations in white matter diffusivity. Changes in care provision and policy are needed to address the disparity in health outcomes for individuals experiencing homelessness and precarious housing.

Author affiliations
[1]Department of Psychaitry, University of British Columbia, Vancouver, BC, Canada
[2]British Columbia Mental Health and Substance Use Services Research Institute, Vancouver, BC, Canada
[3]Division of Neurology, University of British Columbia, Vancouver, BC, Canada
[4]Non-Invasive Neurostimulation Therapies Laboratory, University of British Columbia, Vancouver, BC, Canada
[5]Department of Radiology, University of British Columbia, Vancouver, BC, Canada
[6]Department of Psychology, York University, Toronto, ON, Canada
[7]Department of Psychology, Simon Fraser University, Burnaby, BC, Canada
[8]Department of Anesthesiology, Pharmacology, and Therapeutics, University of British Columbia, Vancouver, BC, Canada
[9]Department of Pediatrics, University of British Columbia, Vancouver, BC, Canada
[10]British Columbia Neuropsychiatry Program, University of British Columbia, Vancouver, BC, Canada

Contributors JLS led the processing and analysis of the neuroimaging data, conducted the statistical analyses and led the writing and revision of the manuscript. FV-R, OL and WM contributed to data collection. DW, RCYC, AET, MLH, WS, DJL and TSF contributed to data curation and quality control. AAJ gave guidance on statistical analyses. WGH and WJP gave guidance on analyses and interpretation. AET, AMB, AR, WGH and WJP contributed to funding, and all authors participated in the writing and revision of the manuscript. WJP was the senior author and guarantor of the work.

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Patient consent for publication Not applicable.

Ethics approval This study involves human participants. The Hotel Study was approved by the research ethics board at the University of British Columbia (H08-00521), the CamCAN study was approved by the Cambridgeshire 2 Research Ethics Committee (10/H0308/50) and the additional healthy control data was derived from a study approved by the University of British Columbia (H13-02340). Informed consent was obtained from all participants, and the planned disclosure of clinically significant findings to participants and care providers was part of the consent process and approved by the Research Ethics Board at the University of British Columbia. Participants gave informed consent to participate in the study before taking part.

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