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Economic Evaluations of Digital Health Interventions: A Bibliometric Analysis and a Review of Methodological Challenges

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Abstract

Background: Digital health interventions (DHI) have been identified as a tool that has the potential to meet the growing demand for healthcare, improve the efficiency and sustainability of healthcare, and increase the accessibility and quality of care. The adoption and use of DHI for healthcare was strongly encouraged during the COVID-19 pandemic, resulting in a sharp increase in the number of DHI-related publications. **Objectives:** The number of DHI's economic evaluations (EE) is significantly smaller, accounting for less than 5% of publications on DHI. However, they are essential for demonstrating DHI's cost-effectiveness relative to comparable healthcare interventions. **Methods/Approach:** We conduct a bibliometric analysis of publications on EE of DHI extracted from the Web of Science Core Collection. **Results:** We analyse 2,308 publications from 2005 to 2023 and present the most influential countries, organisations, journals, and publications along with the corresponding bibliometric networks to explore the existing literature on EE of DHI. Furthermore, we systematise concerns and methodological challenges surrounding the economic justification of DHI. **Conclusions:** This paper aims to build a knowledge base for future research to improve EE of DHI, given that only strong clinical and economic evidence can adequately inform resource allocation decisions and thereby encourage adoption of DHI.

Keywords: economic evaluations; digital health interventions; healthcare management; healthcare innovations; telemedicine; cost-effectiveness; bibliometric analysis

JEL classification: I18, I10, D61, H42, H43
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Introduction

As the global population lives longer and grows older, healthcare spending rises. Average per capita healthcare spending in 2020 significantly increased due to the COVID-19 pandemic (OECD, 2021). The global health crisis of the COVID-19 pandemic has exposed several vulnerabilities of healthcare systems. Digital health interventions (DHI) supported by information and communication technologies (ICT) have been identified as a tool that holds the potential to improve the efficiency, accessibility and quality of care (Busso et al., 2022; Greiwe, 2022; Kovačić et al., 2022; Monaghesh & Hajizadeh, 2020; Osvaldić, 2021; Zoroja et al., 2021).

DHI played a vital role during the COVID-19 pandemic, and their adoption increased notably, given that face-to-face contacts were severely restricted (Monaghesh & Hajizadeh, 2020). Now, a new balance between traditional approaches to care and DHI is being sought to meet increasing health needs despite growing shortages of health care staff and challenges to the financial sustainability of health care systems. The perceived benefits of DHI are improved clinical outcomes, reduced healthcare costs, increased efficiency, and improved sustainability and equity. Concerns slowing DHI adoption include the lack of standards, data privacy and protection, ethical challenges, as well as the lack of reliable evidence on the cost-effectiveness of DHI, leading to uncertainty in resource allocation decision making (Fernández Coves et al., 2022; Hong & Cho, 2023; Kovačić et al., 2022; Manteghinejad & Javanmard, 2021; Stanisavljevic & Tekić Sauerborn, 2024).

While there is widespread consensus that stronger evidence on both clinical effectiveness and economic viability of DHI is key for their faster post-pandemic adoption, providing sound economic evaluations (EE) of DHI is challenging for researchers and policymakers. Recently, researchers have conducted several evidence syntheses on EE of DHI, for example, in secondary stroke prevention (Valenzuela Espinoza et al., 2019), palliative care (Naoum et al., 2021), nursing (Huter et al., 2022), and mental health (Jankovic et al., 2021), all of which highlight either the lack of economic evidence or poor quality of existing economic evidence. Conducting sound EE of DHI is a demanding task (Gomes et al., 2022; Petticrew et al., 2013; Walker et al., 2019) given that they are considered complex health interventions often involving multiple interacting technical components with a variety of types and applications. They are also used in multiple contexts, the target population is a group of people rather than an individual, they have a wide range of outcomes and can have spillover effects, they are susceptible to change and development over time, and outcomes depend not only on the intervention but also on the users, making EE difficult to conduct (e.g., Husereau et al., 2014). Although the number of individual scientific publications on DHI's cost-effectiveness is increasing (Waqas et al., 2020), our research indicates they represent less than 5% of all DHI-related publications. The lack of research on EE of current advancements in healthcare, such as telemedicine and artificial intelligence, is particularly highlighted (dos Santos Silva et al., 2021). More research on the costs and benefits of DHI and the development of clear methodological guidelines for EE are therefore necessary to provide sound evidence of their ability to improve the efficiency and effectiveness of healthcare.

The purpose of this paper contributes to this goal by building a knowledge base for further research: by (1) examining research trends related to EE in the DHI literature, with particular attention to the impact of the COVID-19 pandemic, (2) providing a quantitative and qualitative literature review of existing research by using bibliometric analysis, and (3) undergoing content analysis of studied research to synthesise methodological challenges and issues that need to be addressed to improve EE of DHI.

To achieve the set aims, we analyse 2,308 individual scientific publications from 2005 to 2023 and identify the most influential countries, organisations, journal titles, individual publications, and keywords related to the research on EE of DHI. We proceed by analysing the content of the leading scientific publications to identify key challenges associated with EE of DHI brought forward by the existing body of scientific literature and recommendations on how to overcome them.

We organise this paper as follows: In Section 2, we present the data collection, methodology, and results of the bibliometric analysis. In Section 3, we provide an overview of the methodological challenges and issues related to EE of DHI found through content analysis of the leading publications. In Section 4, we discuss the results, draw conclusions, discuss the limitations of our analysis, and propose directions for further research.

Bibliometric analysis

The empirical section should provide appropriate citations to the methodology used. The paper's argument should be built on an appropriate base of theory, concepts, or other ideas. The research or equivalent intellectual work on which the paper is based should be well-designed. Methods employed should be appropriate.

Data collection

To collect the data for the bibliometric analysis, we first review the relevant terminology in the field of DHI to identify all relevant keywords. The use of ICT in healthcare and health-related fields has evolved over more than five decades, and the terminology used has also changed. Five key terms are used to describe the use of ICT in healthcare (Burrell et al., 2022; Srok & Došenović Bonča, 2024, 2022). 'mHealth' is defined as using mobile technologies for health and health-related fields (WHO, 2011). Telemedicine and telehealth are mostly considered synonyms and describe remote healthcare services used to improve health outcomes and health in general, such as video consultations and remote patient monitoring (WHO, 2010). The term 'eHealth' was introduced to cover on-site and remote health and health-related services, such as websites and electronic health records (WHO, 2016). Digital health is an umbrella term that expands eHealth to include new digital technologies, such as artificial intelligence and robotics, and a broader range of smart devices (WHO, 2021). These five terms are used for the search query in our bibliometric analysis ('ehealth' OR 'e-health' OR 'telemedicine' OR 'telehealth' OR 'digital health' OR 'mhealth' OR 'm-health').

Given that our focus is on EE of DHI, we also review the EE types commonly used in healthcare and applicable to DHI. These primarily include the cost-effectiveness analysis (CEA), which compares incremental costs of interventions and incremental effects that reflect health outcomes, the cost-utility analysis (CUA), which considers both the quantity and the quality of life, and the cost-benefit analysis (CBA), which estimates incremental effects in monetary units (Drummond et al., 2005). The analyses more rarely used are the cost-minimisation analysis, which compares alternative interventions based only on the costs, and the cost-consequence analysis (CCA), which disaggregates all costs and outcomes and allows the decision-maker to determine which are relevant (Drummond et al., 2005). The listed EE are used for the construction of the search query, in addition to synonyms used for EE ('cost-effectiveness' or 'cost-utility' or 'cost-benefit' or 'benefit-cost' or 'cost-consequence' or 'cost-minimisation' or 'cost analysis' or 'economic analysis' or 'economic evaluation' or 'health economics').

An extensive literature search of the Web of Science Core Collection (WOS CC) database, widely used for bibliometric analysis (Visser et al., 2021), was conducted by searching for the identified keywords in the abstract, the title and the keywords of the publications. We searched from 2005 to August 2023. The year 2005 was selected as the starting year because the WHO (World Health Organisation) then announced its resolution on eHealth, which recognised the use of ICT for health and health-related fields as cost-effective, and called on member states to develop long-term plans for the development and use of ICT in health (World Health Assembly, 2005). We found a total of 54,265 publications on DHI, which were restricted to articles, review articles and English-language texts, out of which 2,308 publications dealing with EE of DHI (4.25%) remained for bibliometric analysis.

Methodology

To investigate the 2,308 individual publications on EE of DHI, we conducted a bibliometric analysis and bibliometric network mapping using VOSviewer and R software (Aria & Cuccurullo, 2017; van Eck & Waltman, 2010). Bibliometric analysis provides a set of valuable techniques to investigate the rapidly growing field of DHI, as recognised by several authors in the area (e.g., Waqas et al., 2020; Sikandar et al., 2021; Uribe-Toril, Ruiz-Real and Nievas-Soriano, 2021). The techniques for bibliometric analysis can be grouped into two: (1) performance analysis and (2) science mapping (Donthu et al., 2021). Performance analysis is based on several quantitative and qualitative publication and citation-related indicators. For example, the volume of research published and productivity per active year of publication are quantitative indicators. In contrast, the total number of citations, the average number of citations per year or the average number of citations per publication, the impact factor and the H-index are quality indicators. While performance analysis examines the contributions of research constituents (countries, organisations to which authors are affiliated, journals, individual publications), science mapping focuses on the relationship between the research constituents. This paper uses several science mapping techniques (Donthu et al., 2021; van Eck & Waltman, 2014).

We start by presenting the performance analysis of all publications related to the EE of DHI. We then analyse individual research constituents by combining performance analysis and selected science mapping techniques. We couple the fundamental quantitative and qualitative indicators with bibliometric co-authorship analysis to investigate the countries and organisations to which authors are affiliated. Graphically, the relationships are represented by co-authorship networks. The node's size represents the number of publications per item, and the link's thickness represents the relatedness among the nodes. We then analyse leading journal titles and construct the bibliometric network based on the average publication year to distinguish journal titles from recent publications. In this network, the relatedness is determined by the number of shared references among items, and the node size represents the number of citations per journal title. We continue focusing on influential individual publications and use the bibliographic coupling analysis to group them into clusters based on shared references. Lastly, we analyse keywords. We present the co-occurrence network of author keywords, in which the node's weight represents the number of occurrences of a particular keyword and the link's strength indicates the number of publications in which the two keywords occur together (van Eck & Waltman, 2014). This analysis allows us to identify the most frequently used keywords and the primary focus of individual publications. We also show a keyword trend diagram to present how keyword use changed over time and identify research trends across publication years.

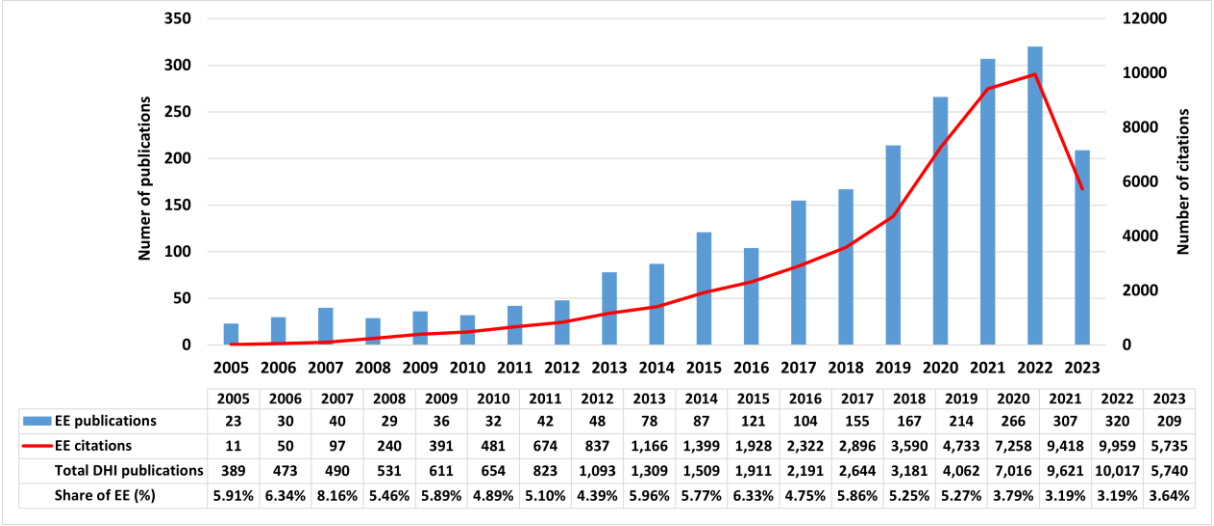
Results

Performance Analysis of all Publications

The yearly number of individual publications and citations on EE of DHI illustrates how the 2,308 papers are distributed over the studied period and how their share changed in the literature addressing DHI (Figure 1). Individual publications on DHI have increased rapidly during the study period. Comparing the number of publications in 2022 (10,017) with those in 2019 (4,062) shows an increase of almost 150%. Although it is evident that DHI have received considerable attention in recent years, particularly during the pandemic, this increased recognition has only been marginally accompanied by an increase in the number of EE publications. Compared to the total number of publications for DHI, the 2,308 publications on EE represent less than 5% of the total. However, the annual number of publications on EE of DHI has been increasing. A greater increase in the number of citations accompanied the increase in publications on EE of DHI. 2019 there were 214 publications and 4,733 citations (22.11 per publication on average). The average number of citations per publication increased to 30.68 and 31.12 in 2021 and 2022, respectively.

Figure 1

Yearly Number of Individual Publications and Citations on EE of DHI, 2005–August 2023



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EE publications	23	30	40	29	36	32	42	48	78	87	121	104	155	167	214	266	307	320	209
EE citations	11	50	97	240	391	481	674	837	1,166	1,399	1,928	2,322	2,896	3,590	4,733	7,258	9,418	9,959	5,735
Total DHI publications	389	473	490	531	611	654	823	1,093	1,309	1,509	1,911	2,191	2,644	3,181	4,062	7,016	9,621	10,017	5,740
Share of EE (%)	5.91%	6.34%	8.16%	5.46%	5.89%	4.89%	5.10%	4.39%	5.96%	5.77%	6.33%	4.75%	5.86%	5.25%	5.27%	3.79%	3.19%	3.19%	3.64%

Source: Author's illustration

Additional performance indicators of publications on EE of DHI are shown in Table 1. The 2,308 individual publications have 53,186 citations in 37,822 citing publications, with an average of 23.04 citations per publication and an H-index of 101. Furthermore, the individual publications originated from 108 countries, 3,957 organisations (affiliations), 12,527 authors, and 850 journal titles. Publications span 84 research areas, with most publications in Health Care Sciences Services, followed by Medical Informatics and Public Environmental Occupational Health, highlighting the interdisciplinary nature of the publications. In addition, more than 4,400 author keywords were used.

Table 1
Performance Indicators of Individual Publications on EE of DHI, 2005–August 2023

Number of publications on DHI	54,265
Number of publications on EE of DHI	2,308
Number of citations	53,186
Average number of citations per publication	23.04
H-index	101
Number of countries	108
Number of affiliations	3,957
Number of authors	12,527
Number of journals	850
Number of research areas	84
Number of keywords	4,414

Source: Author's calculations

Analysis of leading countries and organisations

Among the most productive countries in terms of the number of publications, the United States ranks first, followed by England, Australia, the Netherlands, and Canada. The United States have the highest per capita spending and the largest share of GDP in healthcare spending globally. Furthermore, the United States have a strong biotechnology industry and several renowned universities (e.g., Stanford and Harvard). England is also well known for its renowned universities and health economic organisations (e.g., the London School of Economics, the University of York, the National Institute for Health and Care Excellence). The National Institute for Health and Care Excellence (NICE) provides various guidelines for evaluating medical technologies, diagnostics, pharmaceuticals, and even DHI (NICE, 2022). Furthermore, Australia and Canada are among the countries that first introduced HTA (health technology assessment) national guidelines (Sharma et al., 2021). Therefore, the research output may be linked to the size of healthcare demand and spending, the number of renowned universities and health economic organisations, and the development of EE guidelines. Furthermore, the majority of countries shown in Table 2 are high-income countries. The number of citations per publication among the most productive countries was highest for England (30.78), followed by Canada (27.61) and the United States (25.47).

Table 2
Most Productive Countries

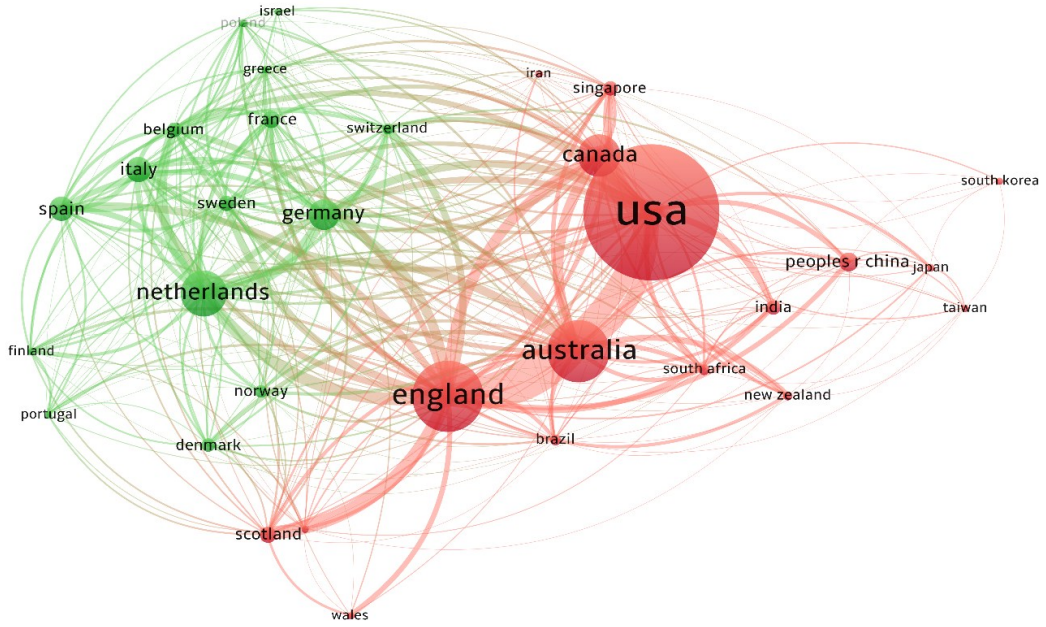
Country	TP	TC	C/P
USA	769	19,587	25.47
England	361	11,110	30.78
Australia	310	6,493	20.95
Netherlands	219	4,373	19.97
Canada	197	5,440	27.61
Germany	137	3,221	23.51
Italy	106	2,048	19.32
Spain	105	1,823	17.36
China	77	1,606	20.86
France	69	1,482	21.48

Note: TP = total publications, TC = total citations, C/P = citations per publication
Source: Author's calculations

We present the collaboration between countries as a co-authorship network of countries in Figure 2. We identify two clusters, the green one comprising European

countries and the red one comprising the United States, Canada, the United Kingdom, Australia, and various non-European countries. Although the most productive countries frequently collaborate, the green cluster also shows numerous collaborations between European countries.

Figure 2
Clustered Networks of Countries Based on Co-authorship Analysis



Source: Author's illustration

In addition to analysing the most productive countries, we also analyse organisations to which authors are affiliated. We list the 10 most cited organisations in Table 3. The most cited organisations were University College London, Oxford University and University of Queensland. On average, publications from the University Hospital of North Norway, Imperial College London, and the University of Southampton were more influential. Almost all influential organisations originate from the leading countries, with English universities accounting for half of the most cited organisations, indicating the dominance of English universities in the area.

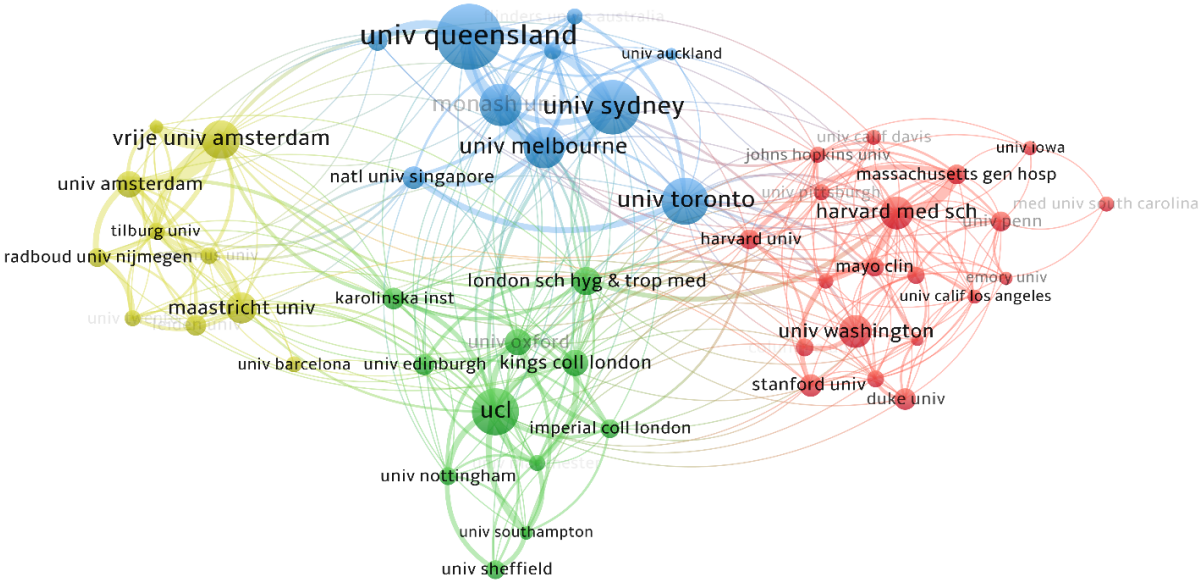
Table 3
Most Cited Organisations

Organisation	Country	TP	TC	C/P
University College London	England	56	2,139	38.20
Oxford University	England	32	1,833	57.28
University of Queensland	Australia	78	1,723	22.09
University Hospital of North Norway	Norway	13	1,522	119.38
Imperial College London	England	14	1,477	105.50
University of Edinburgh	Scotland	25	1,395	55.80
University of Washington	USA	39	1,382	35.44
University of Manchester	England	20	1,378	68.90
University of Southampton	England	16	1,348	84.25
Vrije Universiteit of Amsterdam	Netherlands	46	1,237	26.89

Note: TP = total publications, TC = total citations, C/P = citations per publication
Source: Author's calculations

Figure 3 shows the co-authorship network between organisations. The organisations are divided into four groups, primarily representing collaboration between universities from the same country (blue, Australian; red, the United States and Canada; green, the United Kingdom; yellow, the Netherlands). The clustering shows that the organisations mainly collaborate within their own country.

Figure 3
Clustered Networks of Organisations Based on Co-authorship Analysis



Source: Author's illustration

Analysis of leading journals

The journals with the most citations of publications on EE of DHI are also the journals with the most publications, namely the Journal of Telemedicine and Telecare, Telemedicine and e-Health and Journal of Medical Internet Research (Table 4).

Table 4
Most Productive Journals

Source	TP	TC	C/P	IF (2021)	H index
Journal of Telemedicine and Telecare	142	3836	27.01	6.34	80
Telemedicine and e-Health	132	3724	28.21	5.03	81
Journal of Medical Internet Research	130	5459	41.99	7.08	158
BMJ Open	88	683	7.76	3.01	121
BMC Trials	72	764	10.61	2.28	84
JMIR Research Protocols	59	543	9.20	-	33
JMIR mHealth and uHealth	46	808	17.57	4.95	68
PLOS One	34	1048	30.82	3.58	367
International Journal of Environmental Research and Public Health	29	180	6.21	4.61	138
Contemporary Clinical Trials	24	205	8.54	2.26	65

Note: TP = total publications, TC = total citations, C/P = citations per publication, IF = Impact Factor
Source: Author's calculations

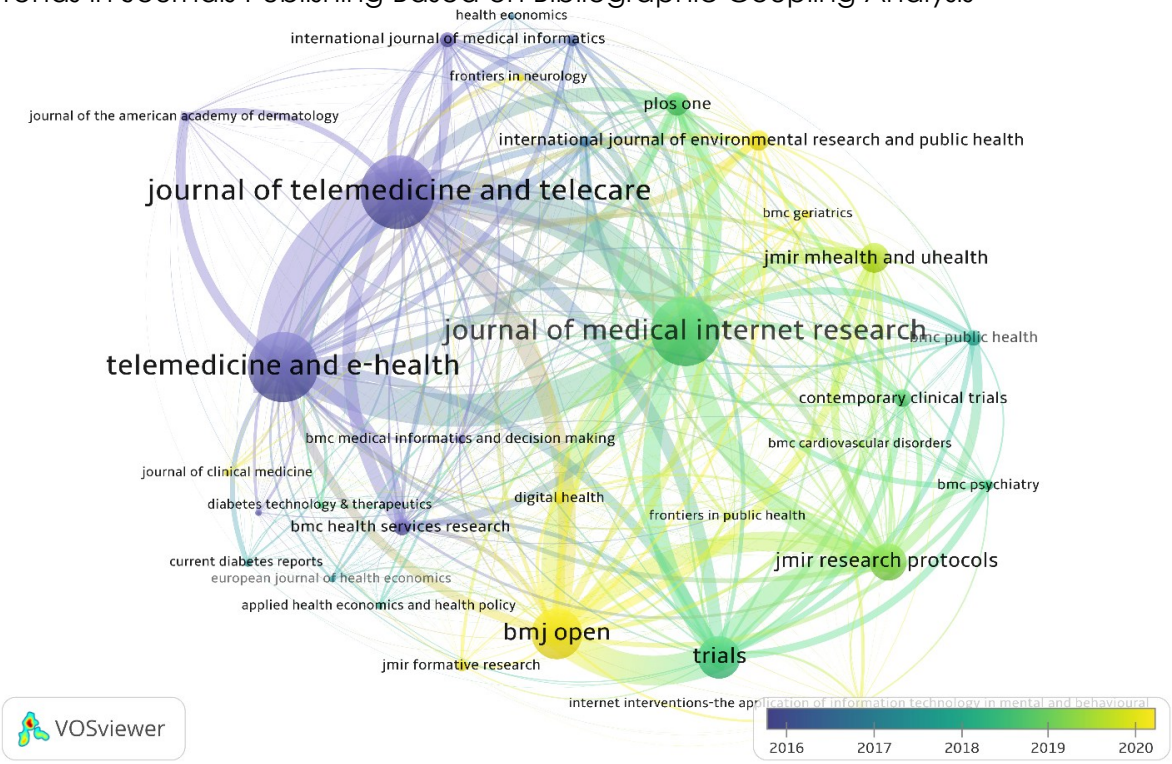
The research focus of the presented journal titles is digital health, and they account for most publications in the field, according to the Bradford Law analysis. The journals

listed have the highest average number of citations per publication, in addition to PLOS One. The journals belong to health informatics, medicine research, and other, mostly multidisciplinary areas. Table 4 also shows the impact factor and the H-index of the journals, which underlines the quality and prestige of the journals in this area.

We present journals linked in a bibliometric network based on the number of shared references in Figure 4. We use overlay visualisation to distinguish journals based on the publication year, with the journal with the most recent publications marked in light green and yellow. The most recent publications were published in multidisciplinary journals, such as BMJ Open, International Journal of Environmental Research and Public Health, and JMIR mHealth and uHealth, suggesting that DHI are gaining recognition in journals with a broader research focus. This is consistent with the multidisciplinary nature of DHI, the greater integration of ICT in different healthcare segments, and the diverse use of digital technologies for health-related care.

Figure 4

Trends in Journals Publishing Based on Bibliographic Coupling Analysis



Source: Author's illustration

Analysis of influential individual scientific publications

Table 5 lists the most frequently cited publications, together with key points related to EE. As expected, almost all of the most frequently cited publications were systematic reviews or other forms of evidence synthesis, as evident from the publication title. Half of the publications had the most citations per year in the last three years, demonstrating the importance of DHI during the COVID-19 pandemic while highlighting the increasing research interest in publications related to EE and DHI.

The publications addressed the effectiveness of different types of DHI (Ekeland et al., 2010; Hilty et al., 2013; Hollis et al., 2017) and their impact on healthcare (Black et al., 2011; Gatchel et al., 2014; Wootton, 2012), as well as issues related to the development, implementation and evaluation of DHI (Aranda-Jan et al., 2014; Michie et al., 2017). Therefore, the most frequently cited publications discuss EE as part of the

methodology for evaluation or address the need for cost-effectiveness in evidence synthesis, supplemental to clinical effectiveness. Out of the most cited publications, Michie et al. (2017), for example, identified the lack of evidence of cost-effectiveness as one of the significant challenges in developing and evaluating DHI while emphasising the importance of the long-term costs and benefits of such interventions and their various impacts on clinical, societal, and health system perspectives. Hilty and colleagues (2013), focusing on telemedicine interventions for mental health, highlighted the various direct and indirect costs and benefits to patients, health systems, and society, pointing to the heterogeneity of research and inconclusive findings on cost-effectiveness. The lack of economic evidence was also noted for telemedicine interventions for chronic diseases, as Wootton (2012) noted, despite being considered essential for developing and accepting telemedicine. Ekeland and colleagues (2010) pointed out some of the challenges of conducting EE and evaluating overall benefits due to the complex nature of telemedicine interventions. Hall and colleagues (2015) indicated the lack of economic evidence and the need for standardised methods for evaluating and comparing mHealth interventions.

Table 5
Most Cited Individual Scientific Publications

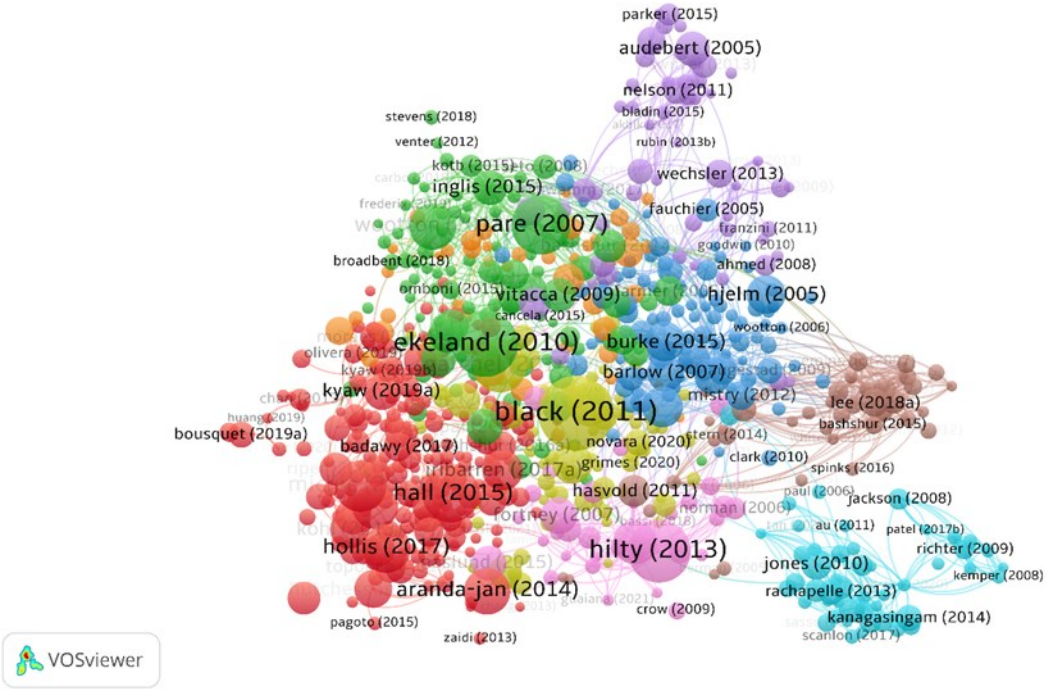
Title	Authors, year	TC	C/Y	BCY	Key points
The impact of ehealth on the quality and safety of health care: a systematic Overview	Black et al., 2011	769	59.15	2013 (90)	Lack of evidence on cost-effectiveness
Effectiveness of telemedicine: A systematic review of reviews	Ekeland et al., 2010	618	44.14	2021 (91)	Methodology issues for EE, lack of evidence on cost-effectiveness, and low-quality evidence
The effectiveness of telemental health: a 2013 review	Hilty et al., 2013	572	52	2021 (111)	Heterogeneity of costs and types of EE used
Systematic review of home telemonitoring for chronic diseases: The evidence base	Paré et al., 2007	500	29.41	2015 (51)	Lack of economic evidence, lack of detailed analysis
Mobile text messaging for health: a systematic review of reviews	Hall et al., 2015	471	52.33	2019 (76)	Lack of cost-effectiveness and cost-benefit evidence
Interdisciplinary chronic pain management: past, present, and future	Gatchel et al., 2014	415	41.5	2020 (75)	Lack of comprehensive reviews of costs and benefits
Developing and evaluating digital interventions to promote behaviour change in health and health care: recommendations resulting from an international workshop	Michie et al., 2017	391	55.86	2022 (81)	Methodology for EE is not appropriate for evaluation of DHI
Annual Research Review: Digital health interventions for children and young people with mental	Hollis et al., 2017	347	49.57	2021 (88)	Lack of evidence on cost-effectiveness

health problems - a systematic and meta-review					
Systematic review on what works, what does not work and why of the implementation of mobile health (mHealth) projects in Africa	Aranda-Jan et al., 2014	329	32.9	2019 (64)	Lack of evidence on cost-effectiveness
Twenty years of telemedicine in chronic disease management - an evidence synthesis	Wootton, 2012	320	26.67	2016 (49)	Lack of evidence on cost-effectiveness

Note: TC = total citations, C/Y = citations per year, BCY = best citation year (number of citations)
Source: Author's calculations

The bibliographic coupling analysis of publications allows us to create a clustered network of publications on EE of DHI based on shared references (Figure 5). We distinguished nine clusters, which mainly revolve around medical fields. The three clusters at the edges are related to specific medical fields and indicate an area of distinct and established research. The purple cluster includes publications in neurology, the brown cluster includes publications in dermatology, and the light blue cluster includes publications on ophthalmology and diabetes. The green cluster represents publications on telemedicine and chronic diseases. The red cluster represents smartphone use and health-related behaviours, and the dark blue and yellow cluster includes various reviews and literature synthesis. The orange cluster in the middle includes publications related to rehabilitation, and the pink cluster includes publications mainly related to mental health.

Figure 5
Clustered network of publications



Source: Author's illustration

Analysis of keywords

Analysis of keywords across publications reveals the 20 most frequently occurring author keywords (Table 6). As expected, the most frequently occurring keywords were the key terms, such as telemedicine and telehealth. Cost-effectiveness was in fifth place, with more than 200 occurrences, followed by health economics, economic evaluation, cost analysis, and cost-benefit. Other author keywords related to EE, such as cost-utility, cost-minimisation, and cost-consequence, were used less.

Table 6
Most occurring author keywords

Keyword	TO	Keyword	TO
telemedicine	741	cost-analysis	90
telehealth	343	covid-19	88
ehealth	299	rct	86
mhealth	260	primary care	82
cost-effectiveness	254	smartphone	74
digital health	130	systematic review	73
health economics	101	cost	69
economic evaluation	99	cost-benefit	61
diabetes	92	depression	57
telemonitoring	92	mental health	56

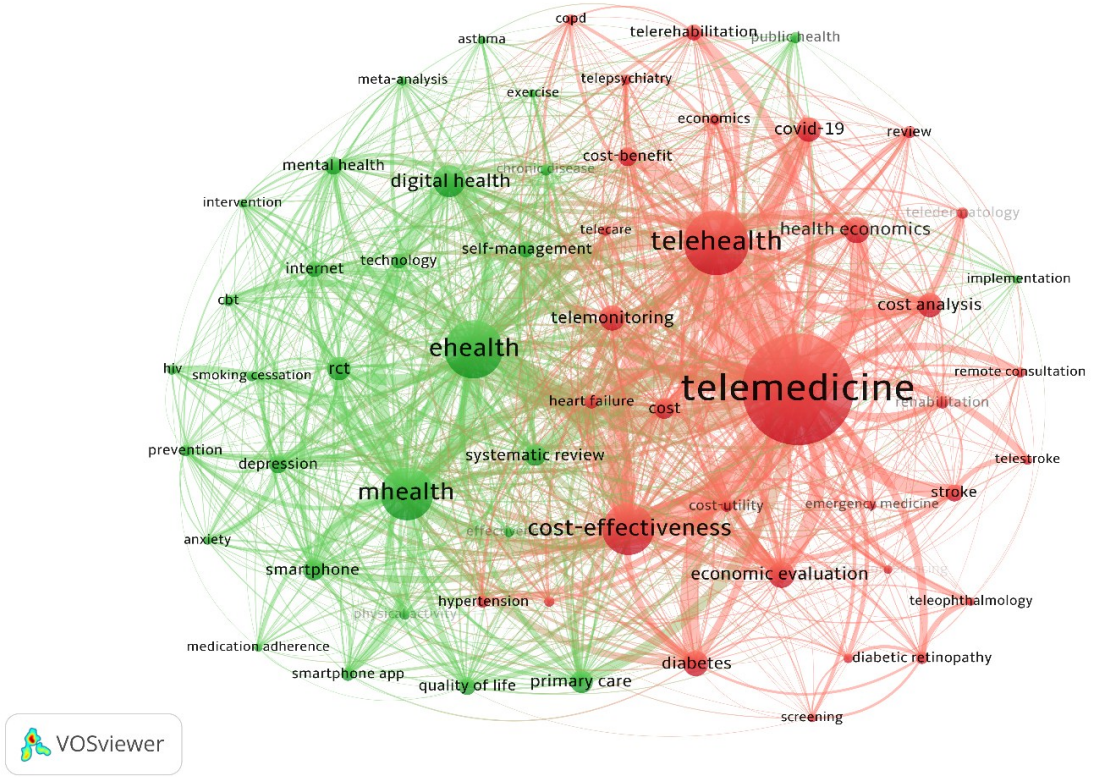
Note: TO = total number of occurrences per keyword
Source: Author's calculations

Figure 6 shows a clustered network of keywords based on their co-occurrence. The red cluster is related to remote healthcare, telemedicine, and telehealth, and the green one is related to eHealth, mHealth, and digital health. On the one hand, the red cluster contains the majority of keywords related to EE but also contains keywords related to medical specialities and chronic diseases (e.g., teledermatology, telerehabilitation, stroke, heart failure, chronic obstructive pulmonary disease, and diabetes).

Chronic diseases account for 41 million deaths each year, or 71% of deaths worldwide, and patients with chronic diseases need frequent check-ups and ongoing engagement. Remote management of chronic diseases has become more critical in the pandemic, because patients with chronic diseases have been susceptible to several complications that can be attributed to COVID-19 (Seixas et al., 2021). Therefore, implementing DHI for continuous monitoring of chronic patients seems particularly attractive.

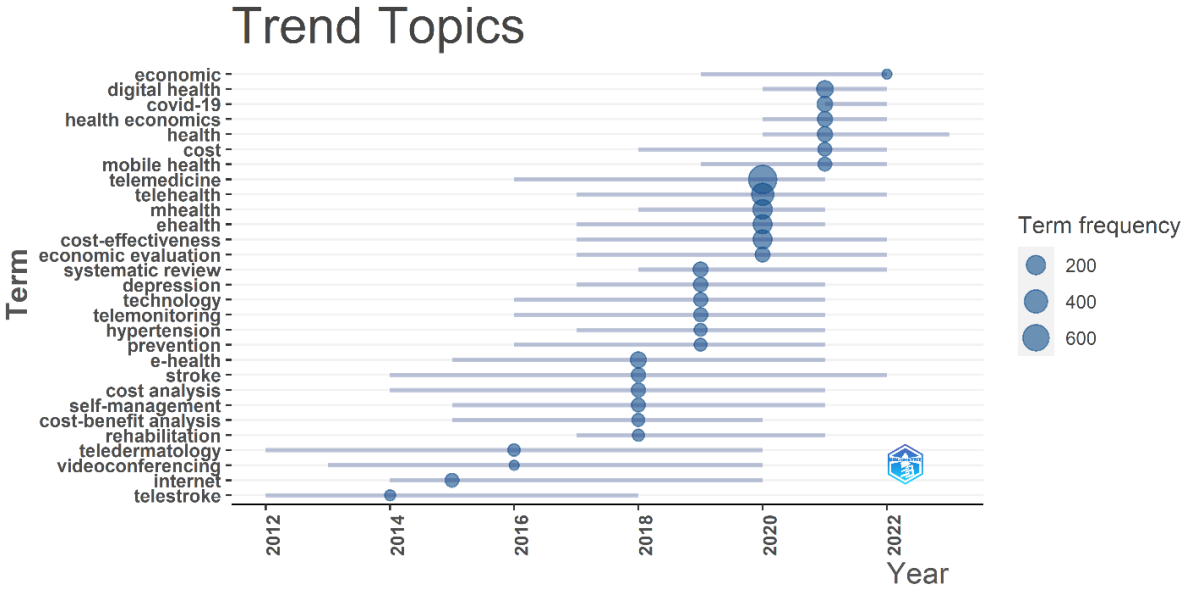
On the other hand, the green cluster emphasises eHealth, digital health and mHealth. It includes keywords such as self-management, smartphone public health, mental health, depression, cognitive behavioural therapy, and physical activity, which have also received more focus lately due to the COVID-19 pandemic (Goldberg et al., 2022). We also present the timeline of keyword usage (Figure 7).

Figure 6
Clustered network of keywords



Source: Author's illustration

Figure 7
Topic trend diagram from 2010 to 202



Source: Author's illustration

Content analysis of individual publications on EE of DHI

To synthesise methodological challenges and issues to EE of DHI, we have undergone content analysis of both the most influential publications and other relevant papers

(Bergmo, 2015; Gomes et al., 2022; Husereau et al., 2014; Jankovic et al., 2021; Kolasa & Kozinski, 2020; McNamee et al., 2016; Michie et al., 2017; C. Snoswell et al., 2017).

One of the key issues is the choice of the perspective in analysis. Most influential publications highlight the need to account for the variety of costs, savings, and benefits generated at a wider, societal level, due to the multiple effects and diverse characteristics of DHI (Aranda-Jan et al., 2014; Ekeland et al., 2010; Michie et al., 2017). The various non-health benefits are an essential feature of DHI, and they can be more substantial than pharmaceuticals or medical devices (Gomes et al., 2022). The societal perspective, in contrast to the usual healthcare payer perspective, which allows the inclusion of costs and benefits to all stakeholders, is thus recommended to adequately capture DHI's overall impact (Gomes et al., 2022; C. Snoswell et al., 2017).

Another critical challenge arises due to the variety of outcome measures used to express the effects of health interventions, such as quality-adjusted-life-years, clinical outcomes, and monetised benefits. On the one hand, heterogeneity in outcome measures reduces the comparability of results. On the other hand, not all outcome measures appropriately capture all health and non-health effects of DHI (Gomes et al., 2022; Hall et al., 2015; McNamee et al., 2016; C. Snoswell et al., 2017; Wootton, 2012).

The choice of adequate outcome measures in EE of DHI is linked with the choice of an appropriate EE method. The commonly used methods, i.e., CEA and CUA, consider only health-related benefits and cannot account for all DHI benefits for all stakeholders. CBA and CCA are thus suggested to account for the broad range of costs, benefits, and societal values that can be easily translated from research to resource allocation decision-making (Gomes et al., 2022; C. Snoswell et al., 2017).

Another challenge is choosing a comparator. An alternative intervention, which DHI substitutes or replaces, can be a non-digital intervention, a competing technology, the 'standard care', or a no-intervention (Gomes et al., 2022; Huter et al., 2022). This implies that a sound EE should consider all relevant comparators (Husereau et al., 2014; Jankovic et al., 2021). However, given that this is unattainable in practice due to time constraints and cost, reliability can be increased by incorporating stakeholders' and decision-makers' perspectives on the most relevant comparators and cost and value assessment (Harst et al., 2020).

In addition to selecting the appropriate comparators, the specification of the time horizon is also important. One challenge is linked to contrasting the high initial investment in DHI to the benefits accumulated over long periods. The time horizon needs to be selected to appropriately capture the declining marginal cost of adding additional beneficiaries of DHI. Another issue is related to the technology development over time and both initial acceptance and long-term adherence by the targeted user groups (Ahmed et al., 2023).

The issues encountered and discussed above are related to the lack of appropriate guidelines for EE of DHI (Ekeland et al., 2010; Gomes et al., 2022; Hall et al., 2015; Michie et al., 2017). While there is a growing body of various guidelines from relevant agencies for DHI evaluation, the existing guidelines remain mostly generic and focused on some aspects of telemedicine or mHealth but fail to provide a more detailed analytical framework for estimating clinical or economic outcomes (Kolasa & Kozinski, 2020). As a result, most researchers continue to adopt recommendations that apply primarily to EE of pharmaceuticals, such as CEA or CUA, and also adopt the payer perspective when evaluating DHI despite growing concerns that this is not the right approach for DHI (Gomes et al., 2022; C. Snoswell et al., 2017).

The discussed challenges and the diversity of DHI lead to heterogeneity of existing research, poor quality, limited transferability, and complex evidence synthesis (Aranda-Jan et al., 2014; Hall et al., 2015; Husereau et al., 2014; Jankovic et al., 2021).

Discussion and Conclusion

This paper examined the research trends related to EE in the DHI literature. The bibliometric analysis has highlighted the recent interest in the novel research area of EE of DHI, evidenced by the increase in publications and a significant increase in citations. However, the research also indicates that publications on EE of DHI represent less than 5% of all DHI-related publications.

A quantitative and qualitative literature review has shown significant heterogeneity across publications related to EE of DHI, and the publications are multidisciplinary. Most publications come from Health Services, Medical Informatics and Public Health research. The number of publications by country and organisation and the number of citations appear to be related to the country's health spending and the influence of organisations and universities involved in health-related research, with the United States and England leading in the number of publications and citations. The leading journals, namely the Journal of Telemedicine and Telecare, Telemedicine and e-Health, and Journal of Medical Internet Research, were subject-specific and dealt with telemedicine and digital health. However, more recently, publications have also been published in multidisciplinary journals such as BMJ Open, reflecting the integration of DHI in different contexts, from improving health services to personal health counselling through smartphone apps. The most influential publications addressed the use of DHI for patients with chronic diseases and chronic pain (Gatchel et al., 2014; Paré et al., 2007; Wootton, 2012), mental health (Hilty et al., 2013; Hollis et al., 2017) and well-being (Hall et al., 2015). The most influential publications also addressed the effectiveness of different types of DHI and their impact on healthcare (Black et al., 2011; Ekeland et al., 2010), as well as issues related to the development, implementation and EE of DHI (Aranda-Jan et al., 2014; Michie et al., 2017).

The keywords used also show the diversity of terms, the different types of DHI, and various applications in different health-related contexts. The established research topics relate to telemedicine interventions, mainly chronic diseases, rehabilitation and remote consultations. More recently, emerging research is focused on using smartphones and various digital technologies, particularly concerning mental health and well-being (e.g., Goldberg et al., 2022). This is consistent with the development and acceptance of smartphone apps for various health-related purposes, from guiding physical activity and assisting in maintaining health habits to providing immediate mental health help and support during the lockdown caused by the COVID-19 pandemic (Ahmed et al., 2023; Fernández Coves et al., 2022; Goldberg et al., 2022).

The performed content analysis revealed a notable lack of sound EE of DHI. We synthesised several methodological challenges and issues that need to be addressed to inform decision-making better and increase the adoption of DHI. The content analysis of the most cited publications and recent research in this area found a lack of evidence on the cost-effectiveness of DHI, poor quality of existing evidence, the need for more appropriate methodology and missing guidelines on the choice of relevant comparators, perspective of the EE, method as well as relevant outcomes and time horizon to capture all relevant costs and benefits (e.g., Bergmo, 2015; Gomes et al., 2022; Husereau et al., 2014; Jankovic et al., 2021; Kolasa & Kozinski, 2020; McNamee et al., 2016; Michie et al., 2017; Snoswell et al., 2017).

To date, most research has focused on the diversity of DHI and its impact on health outcomes. Still, EE are receiving more attention because of their ability to provide evidence for health decision-making, government reimbursement, and attracting investment and funding (e.g., Busso et al., 2022; Gega et al., 2022; Gomes et al., 2022; Huter et al., 2022; Kolasa & Kozinski, 2020; McNamee et al., 2016; Michie et al., 2017; C. Snoswell et al., 2017; C. L. Snoswell et al., 2020). DHI represents a way to transform overburdened health systems and are attracting much research interest. Therefore, EE will undoubtedly play a critical role in the widespread adoption of DHI.

In this paper, we have shown that poor economic evidence and a lack of sound EE of DHI are essential obstacles to adopting DHI. To pave the way forward, the outlined methodological issues must be resolved. Based on our findings, we advocate the development of clear guidelines specifically for EE of DHI and incorporating qualitative research in addition to quantitative research to address the stakeholders' and decision-makers' requirements and perceptions on all relevant elements of EE of complex interventions such as DHI.

Our literature search was limited to a single database and was impacted by the choice of keywords, language, and article type. Future research could consider focusing on specific types of DHI and their impact on public health.

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