EXPLORING NEW HORIZONS

CHALLENGES AND OPPORTUNITIES FOR EHEALTH IN GERIATRIC REHABILITATION

JULES KRAAIJKAMP

Exploring New Horizons

Challenges and opportunities for eHealth in Geriatric Rehabilitation

Jules Kraaijkamp

COLOPHON

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Academic network for research in elderly care.

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Caregivers, policy makers, researchers, students, residents and relatives work together to improve the quality of care and quality of life for vulnerable older people. The UNC-ZH is a regional platform, inspirator and learning network for innovation in long-term care. Research, education and training, and practice are closely related.

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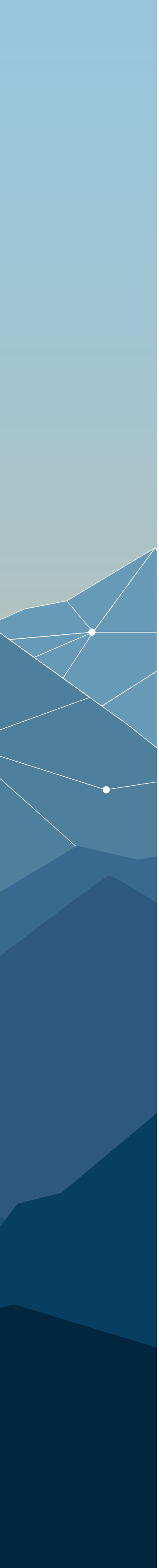

1

General introduction

GENERAL INTRODUCTION

As the world's population ages, the number of people aged over 80 years is rising swiftly [1]. The process of aging is not fixed. While most older adults are relatively fit and can live independently, other suffer from age-associated conditions such as frailty and multimorbidity[2, 3]. Such older adults are prone to functional decline and have an increased risk of adverse outcomes like stroke or falls which can lead to acute hospitalization[4].

Geriatric rehabilitation

Geriatric rehabilitation is an important cornerstone in healthcare systems that enables older adults to (partly) regain their independence and participation after an acute hospitalization. Geriatric rehabilitation is defined as a multidimensional approach comprising diagnostic and therapeutic interventions that focus on optimizing functional capacity, promoting activity and preserving functional reserves and social participation in older people with disabling impairments[5, 6]. Based on the conditions that precede admission to geriatric rehabilitation, specific diagnosis groups can be distinguished such as stroke, fractures, elective orthopaedic surgery, heart failure, chronic obstructive pulmonary disease or cancer[7]. The imminent shortage of staff, and the steep increase of older frail adults are putting pressure on the accessibility and quality of geriatric rehabilitation[8]. New strategies such as pre-rehabilitation, early discharge and outpatient geriatric rehabilitation are needed to sustain the delivery of effective geriatric rehabilitation. In addition, the use of eHealth has the potential to enhance both rehabilitation outcomes and efficiency simultaneously. A case study illustrating the current situation of an admission to geriatric rehabilitation is presented below:

Case study

Mr Peters is a 74-year-old man who has recently suffered a stroke and is admitted to geriatric rehabilitation. Upon admission, Mr peters presented with significant fatigue and decreased physical capacity. His mobility is very limited, and he required support for activities of daily living, such as dressing and bathing.

Mr Peters has made considerable progress during his rehabilitation. His capacity is increasing so that he can walk short distances with a walker and often does not need help with dressing. His main goal now is to continue to improve his capacity so that he can regain his independence to walk outside and thus return home. He would like to have more therapy, but the physiotherapist's schedule is full during the week. And there is no therapy at weekends.

Jack, the physiotherapist, aims to intensify therapy for Mr. Peters; however, his tight schedule poses a challenge. Although Jack is keen on providing additional exercises for Mr. Peters outside of therapy sessions, he has concerns about his ability to adequately monitor these exercises.

eHealth

eHealth can be defined as "*the use of digital information and communication to support and/or improve health and healthcare*"[9]. eHealth interventions vary widely, from relatively simple approaches such as video communication, to complex treatment applications involving virtual reality and robotics.

Although the use of eHealth in geriatric rehabilitation can be seen as promising and needed, successful adoption of eHealth in clinical practice of geriatric rehabilitation is lagging behind. Several reasons for this can be identified. First, to successfully implement eHealth in geriatric rehabilitation, scientific and practical evaluation of effective eHealth is key[10, 11]. However, evidence on effective eHealth for older adults in geriatric rehabilitation is scarce, fragmented and often lacks usability outcomes. The lack of usability outcomes is particularly concerning given that there are certain age-related barriers that may hinder the use of eHealth[12, 13].

Second, Healthcare professionals play an important role in the successful adoption of eHealth, but implementation is often time-consuming, complex and requires a change of workflow[14-16]. Third, due to the ever-changing landscape of eHealth interventions, it is difficult for healthcare professionals to assess which eHealth applications are effective and suit their local context[17]. As a result, the uptake of eHealth by professionals is often sub optimal[18].

eHealth in geriatric rehabilitation

eHealth has the potential to address current challenges and improve rehabilitation outcomes in geriatric rehabilitation in different ways and at different stages of the patient journey. In the diagnostics phase, the assessment of the current status and prediction of functional recovery is important for the content and organization of a rehabilitation program and setting patient expectations. In current practice, this prediction is often assessed using clinical observational scales. However, the use of validated clinical observational scales has limitations, mainly due to a dependence on the skill and experience of the assessor for scoring and interpretation[19]. Wearable sensors pose the ability to objectively measure and record human movement, such as balance or gait parameters[20]. Compared with clinical scales, such as the USER, wearable sensors often assess different domains of the International Classification of Function, Disability and Health[21]. For example, a wearable sensor can assess postural sway (ICF domain: body functions & structures), while the USER evaluates mobility (ICF domain: activities). Data derived from wearable sensors might complement clinical scales, by integrating data from different ICF domains, to improve the prediction of functional recovery.

In the treatment phase, goal setting is crucial to create a treatment plan tailored to the patient's needs and capacity[22]. This applies particularly to improving physical activity, as it enables patients to regain their independence. Traditional methods such as self-report questionnaires to assess physical activity, such as the Seven-Day Physical Activity Recall Questionnaire, often overestimate physical activity and are often subject to recall bias[23]. Furthermore, self-reported questionnaires often fail to capture low-intensity physical activity and sedentary behaviour, which is common among older adults in geriatric rehabilitation[24]. Wearable sensors, like accelerometers can reliably and objectively assess physical activity and sedentary behaviour[25]. This enables healthcare providers to accurately monitor a patient's individual rehabilitation, allowing them to assess whether the current therapy is leading to anticipated results, provide personalized feedback and if needed to adjust the current therapy. It also allows the assessment of physical activity and sedentary behaviour outside of therapy or in the patient's own home, which may more accurately reflect abilities in everyday life[26].

While the above solutions hold potential, there is insufficient scientific evidence of their benefits to support them, and insufficient knowledge of the barriers and facilitators for successful implementation. Furthermore, a better understanding of the experiences and needs of healthcare professionals is lacking, which hampers the adoption of eHealth in geriatric rehabilitation.

AIM OF THIS THESIS

The current thesis describes the results of the EAGER study (EHeAlth in GEriatric Rehabilitation). The overall aim of the EAGER study is to create a foundation for evidence & practice-based eHealth in geriatric rehabilitation and to investigate a promising eHealth type; wearable sensors. In this thesis the following research questions were addressed:

1. Which elements are important for effective use of eHealth in Geriatric rehabilitation?
2. To which extent can wearable sensors enhance the prediction of functional recovery and monitoring of individual progress in geriatric rehabilitation?

OUTLINE OF THIS THESIS

The outline of this thesis follows the roadmap established by the EAGER study. This roadmap outlines the necessary steps to accomplish the primary objective of the EAGER study—namely, to create a foundation for evidence- and practice-based eHealth in geriatric rehabilitation. The roadmap is presented in Figure 1.

Figure 1: roadmap EAGER study

Part 1: Elements for effective use of eHealth in geriatric rehabilitation

Chapter 2 describes a systematic review on the effectiveness, feasibility and usability of eHealth in geriatric rehabilitation. This study assesses the current scientific evidence on eHealth in geriatric rehabilitation. In **chapter 3** the perspectives of healthcare professionals on eHealth in geriatric rehabilitation are described. In an international cross-sectional study, a web-based survey was used to explore the experiences and needs of healthcare professionals regarding the use, benefits, feasibility and usability of eHealth in geriatric rehabilitation. **Chapter 4** combines the knowledge of chapter 2 and chapter 3 to achieve consensus on the use and evaluation of geriatric rehabilitation on a global scale. A two-round online Delphi study was conducted in which healthcare professionals with experience in geriatric rehabilitation eHealth participated to rate statements on three key topics related to geriatric rehabilitation eHealth: use of eHealth, domains of eHealth, and scientific evaluation of eHealth.

Part 2: Wearable sensors to enhance geriatric rehabilitation

In **Chapter 5** objectively measured postural sway using a wearable sensor, in combination with a clinical scale, was used to determine if it could improve the prediction of functional recovery at discharge in older adults recovering from stroke during geriatric rehabilitation. In **chapter 6** wearable sensors were used to quantify physical activity, sedentary behaviour and accompanying patterns of change in older adults recovering from stroke during geriatric rehabilitation. **Chapter 7** describes a cohort study using wearable sensors to quantify movement patterns, identify groups based on movement patterns, and correlate functional and mental health characteristics in older adults recovering from hip fracture following geriatric rehabilitation. Finally, in **chapter 8**, the main findings of this thesis and the implications for clinical practice, education and research are discussed.

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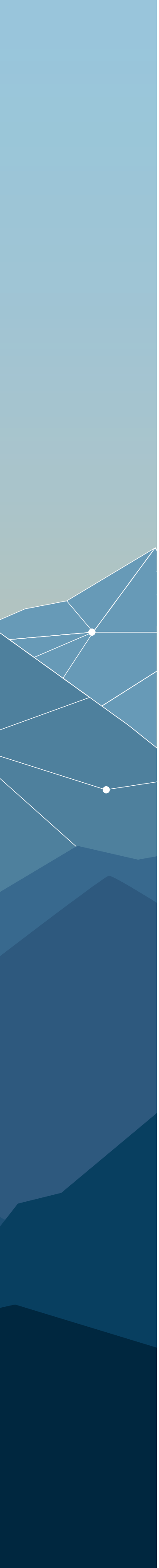

Part 1

Elements for effective use of eHealth in geriatric rehabilitation

2

eHealth in geriatric rehabilitation: a systematic review of effectiveness, feasibility and usability

Jules J.M. Kraaijkamp, Anke Versluis, Anke Persoon, Eléonore F. van Dam van Isselt, Niels H. Chavannes, Wilco P. Achterberg.

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ABSTRACT

Background: eHealth has the potential to improve outcomes such as physical activity or balance in older adults receiving geriatric rehabilitation. However, several challenges such as scarce evidence on effectiveness, feasibility, and usability hinder the successful implementation of eHealth in geriatric rehabilitation.

Objective: The aim of this systematic review was to assess evidence on the effectiveness, feasibility, and usability of eHealth interventions in older adults in geriatric rehabilitation.

Methods: We searched 7 databases for randomized controlled trials, nonrandomized studies, quantitative descriptive studies, qualitative research, and mixed methods studies that applied eHealth interventions during geriatric rehabilitation. Included studies investigated a combination of effectiveness, usability, and feasibility of eHealth in older patients who received geriatric rehabilitation, with a mean age of ≥70 years. Quality was assessed using the Mixed Methods Appraisal Tool and a narrative synthesis was conducted using a harvest plot.

Results: In total, 40 studies were selected, with clinical heterogeneity across studies. Of 40 studies, 15 studies (38%) found eHealth was at least as effective as non-eHealth interventions (56% of the 27 studies with a control group), 11 studies (41%) found eHealth interventions were more effective than non-eHealth interventions, and 1 study (4%) reported beneficial outcomes in favor of the non-eHealth interventions. Of 17 studies, 16 (94%) concluded that eHealth was feasible. However, high exclusion rates were reported in 7 studies of 40 (18%). Of 40 studies, 4 (10%) included outcomes related to usability and indicated that there were certain aging-related barriers to cognitive ability, physical ability, or perception, which led to difficulties in using eHealth.

Conclusion: eHealth can potentially improve rehabilitation outcomes for older patients receiving geriatric rehabilitation. Simple eHealth interventions were more likely to be feasible for older patients receiving geriatric rehabilitation, especially, in combination with another non-eHealth intervention. However, a lack of evidence on usability might hamper the implementation of eHealth. eHealth applications in geriatric rehabilitation show promise, but more research is required, including research with a focus on usability and participation.

Keywords: Geriatric rehabilitation, eHealth, effectiveness, feasibility, usability, systematic review

INTRODUCTION

The world’s population is aging rapidly. Currently, 143 million people are aged 80 years or older, and this number is expected to rise to around 426 million in 2050[1] . Although many older adults are relatively fit, functional decline, multimorbidity, and geriatric syndromes such as frailty or falls are common in older adults[2,3]. A combination of these age-associated conditions triggers an increased risk of adverse outcomes such as hospitalization, functional impairments, and even mortality[4.] Postacute care such as geriatric rehabilitation aims to diminish these age-associated risks. Evidence shows that geriatric rehabilitation can improve functional outcomes and reduce nursing home admissions and mortality[5,6 .] On the other hand, the rapidly aging populations and lack of staff are putting pressure on the quality, accessibility, and affordability of geriatric rehabilitation. In regard to these problems, the use of eHealth can be seen as important and promising, as it has the potential to simultaneously improve both rehabilitation outcomes and efficiency.

eHealth can be defined as “the use of digital information and communication to support and/or improve health and health care” [7]. Some examples of eHealth are video communication, exergames (ie, active video games), and mobile apps. Although eHealth can be seen as important and promising, successful implementation of eHealth interventions in geriatric rehabilitation is complex, can be time consuming, and involves a variety of determinants on multiple levels[8-10]. To safely and successfully implement eHealth in geriatric rehabilitation, scientific evaluation of eHealth is key[11,12.] Three important outcome measures for the evaluation of eHealth in geriatric rehabilitation can be identified: effectiveness, feasibility, and usability[9,13].

In terms of effectiveness, previous reviews show that eHealth can improve physical activity, gait, and balance in community-dwelling older adults[14-17] . However, the evidence on effective eHealth in geriatric rehabilitation is scarce and fragmented. To our knowledge, no prior reviews have examined the effectiveness of eHealth in geriatric rehabilitation.

To better understand how eHealth can be used safely, feasibility testing is an important first step[18,19]. The aim of feasibility testing is to “determine whether an intervention is appropriate for further testing”[20,21,] but a general accepted standard on feasibility testing is lacking. Examples of factors that can be addressed in feasibility testing are adverse events, adherence, and acceptability[10.].

Additionally, usable eHealth is also an important prerequisite for successful implementation[13,19,22]. Usability can be defined as “the extent to which a system, product, or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use"[23]. For older adults receiving geriatric rehabilitation, usability is especially crucial, since there are certain age-related barriers that may hamper the usability of eHealth[24-26]. These barriers can be categorized into 4 patient-related domains: cognition, physical ability, perception, and motivation[27]. For example, poor vision can make it harder to distinguish certain icons on screens, or cognitive impairment might lead to problems understanding certain eHealth interventions. Often, eHealth is insufficiently tailored to these age-related barriers[28].

Therefore, a systematic review of eHealth in geriatric rehabilitation including the concepts feasibility, usability, and effectiveness was needed. This systematic review can help speed up the implementation process of eHealth and ensure successful adoption of eHealth overall. The aim of this review was to assess evidence on the effectiveness, feasibility, and usability of eHealth interventions in older adults in geriatric rehabilitation.

METHODS

Study Registration and Protocol

This systematic review is registered at PROSPERO, with registration number CRD42019133192[29]. This systematic review was based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement, which is an evidence-based minimum set of items used for reporting in systematic reviews and meta-analyses[30]. The complete checklist for this review can be found in Multimedia Appendix 1.

Types of Studies and Participants

In this review, we included randomized controlled trials, nonrandomized studies, quantitative descriptive studies, qualitative research, and mixed methods studies. We excluded systematic reviews, abstracts, editorials, and non-English and nonpeer-reviewed studies. Studies examined older patients with a mean age of ≥70 years who received geriatric rehabilitation, which is in line with consensus statements on the organization and delivery of geriatric rehabilitation across Europe[31]. Because there is variability between countries' health care systems and consequently also between countries' provisions of geriatric rehabilitation[31,32], we included studies in different types of settings such as (geriatric) rehabilitation centers, skilled nursing facilities, hospitals, or ambulatory settings. Studies that included patients with a chronic disease with no acute functional decline were excluded.

Interventions and Outcomes

Studies investigated eHealth interventions applied during postacute geriatric rehabilitation. Outcome measures related to the effectiveness of interventions were included if they could be classified based on the World Health Organization's International Classification of Functioning, Disability, and Health (ICF) model[33], which covers the following domains: body functions and structure, activities, participation, environmental factors, and personal factors. For the purpose of this review, we chose to specify feasibility within the following domains: adverse events, adherence, and exclusion rates. Usability outcome measures were classified based on the MOLD-US framework, which is an evidence-based framework of aging barriers that influence the usability of eHealth in older adults and includes 4 categories: cognition, motivation, physical ability, and perception[27]. We included both primary and secondary outcome measures.

Sources and Search Strategy

On March 9, 2019, March 10, 2019, and January 11, 2021, we searched the following databases: MEDLINE, PsycINFO, EMBASE, EMCARE, Cochrane Library, Web of Science, and Central databases. For this review, 3 separate search strings were compiled. The first focused on the effectiveness, the second focused on the feasibility, and the third focused on the usability of eHealth interventions in geriatric rehabilitation. The search string focusing on effectiveness included keywords related to older adults, rehabilitation, and eHealth interventions. Studies were identified when at least 2 of 3 keywords were present. The search strings focusing on feasibility and usability included an additional keyword related to feasibility or usability. In both search strings, keywords were combined using MeSH terms using the Boolean operations "or" and "and." The complete search strings can be found in Multimedia Appendix 2.

Selection of Studies and Data Extraction

We first screened titles of the identified studies. The abstracts of all potentially relevant studies were then screened by 2 authors independently. Next, full texts were obtained and reviewed by the same authors. We excluded studies that did not meet the inclusion criteria. Disagreements between the 2 authors were discussed until a consensus was reached. If a disagreement could not be resolved, a third reviewer was consulted. Data extraction was performed using Covidence, which is an online systematic review management tool[33] . In Covidence, a data extraction form was constructed that included details of publication (ie, author, year, title, country of study, and funding), study design, methods (ie, inclusion and exclusion criteria, population, randomization, statistical analysis, and outcome measures), sample characteristics (ie, age, number of participants, gender, and diagnosis), eHealth intervention (ie, name of intervention, goal of intervention, delivery of intervention, and application of intervention), and primary and secondary outcomes. As the complexity of eHealth interventions influences implementation, we sorted eHealth interventions ranging from simple (ie, video communications, health sensors, or gateways) to complex (ie, robotics, exergames, or virtual reality)[9,35.] One author then extracted the data. A subset of the data (10% of included studies) was also extracted by a second author to check interrater reliability.

Quality Appraisal

The quality of included studies was assessed using the Mixed Methods Appraisal Tool (MMAT)[36], which allowed quality assessment across different study designs. The MMAT is a critical appraisal tool specifically designed to assess the quality of 5 types of study designs: qualitative research, randomized controlled trials, nonrandomized studies, quantitative descriptive studies, and mixed methods studies. For each study design, the MMAT provides 5 quality criteria that must be rated with "Yes," "No," or "Can't tell." Since the calculation of an overall score from the ratings of each criterion is discouraged[36,37] , we reported a separate score for each rating. Nevertheless, an overall score was reported, because it provides a general picture of study quality. Studies were not excluded based on study quality [36] . For the randomized controlled trials and nonrandomized designs, we rated the criterion "Are there complete outcome data?" as "No" when the drop-out rate was over 20%[38] . In nonrandomized designs, we rated the criterion "Are the confounders accounted for in the design and analysis?" as "No" when there was no description of additional therapy offered during the study, functional status, or cognitive status. Quality assessment was carried out by one author, and 10% of the included studies were selected at random and additionally assessed by a second author to check interrater reliability.

Data Analysis and Data Synthesis

In studies that reported outcomes related to effectiveness and included a control group, a narrative synthesis was conducted using a harvest plot[39] . In the harvest plot, primary and secondary outcomes were described and color coded based on ICF domain. For each study, the bars in the harvest plot indicated the total results for the different ICF domains, and the height of the bars represented the methodical quality based on the MMAT. When a study reported multiple consistent results within the same ICF domain, the results were combined in 1 bar. If a study reported conflicting results within the same ICF domain, both results were presented. Randomized controlled trails were represented by a thick contour around bars. A meta-analysis was not feasible since the included studies were too heterogeneous with regard to population, intervention, and outcome measures.

RESULTS

Study Selection

The search strategy identified a total of 7635 unique records. After exclusion of records based on title and abstract, 331 records remained. During full-text screening, a further

291 records were excluded, resulting in the inclusion of 40 studies in this review. Reasons for exclusion are presented in the study flowchart shown in Figure 1. In 12 cases, a third reviewer was needed to achieve consensus during the process of study selection.

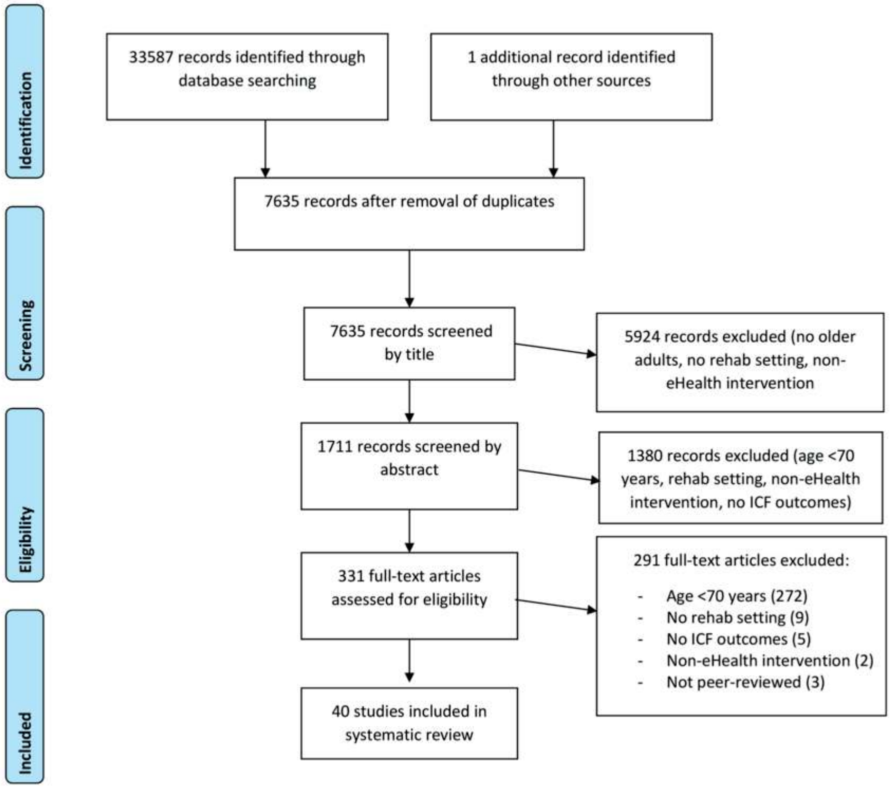

Figure 1. PRISMA flow diagram of search strategy results. ICF: International Classification of Functioning, Disability, and Health.

Study characteristics are shown in Table 1. Of the 40 included studies, 18 (45%) were randomized controlled trails[40-57] , 2 (5%) had a mixed methods design[58,89,] 1 was a qualitative study[60] , and 19 (48%) had a quantitative nonrandomized design[61-79] , of which 9 studies (of 19, 47%) included a control group[53,61-68,79] . Of 40 studies, 17 studies (43%) were conducted in a hospital setting[41-44,46,50,51,55-57,62,64-66,68,71] . Of the 17 hospital-setting studies, 12 (71%) were conducted in a dedicated hospital-rehabilitation unit[41-44,46,50,51,55,56,64,71,79], 2 (12%) were in a hospital-stroke unit[57,68], and 1 (6%) was conducted in a geriatric day hospital[62] . Of the 40 studies, 10 (25%) were conducted in an ambulatory setting[47,48,52-54,60,69,75,76,78], 9 studies (23%) took place in a geriatric rehabilitation setting[18,45,49,58,60,67,71,77,78], 2 studies (5%) were at a tertiary rehabilitation center[60,73], 1 study (3%) was at a skilled nursing facility [77], and 2 studies (5%) did not report the setting[67,72].

Table 1. Study characteristics.

Author; year; country	Design	Diagnosis; n; setting	Age (SD); female (%)	Intervention	Use of intervention	Primary outcome domain (primary outcome measure)	Secondary outcome domain(s)
Barnason[53] 2009 UnitedStates	RCT[a]	Cardiac n=55 Ambulatory	71.6 (5.1) 16	Video communication in combination with non-eHealth vs usual care	Daily use, subjects responded to assessment queries, were provided with strategies	Effectiveness, activities (other)	Effectiveness, participation
Backman[59] 2020 UnitedKingdom	Mixed methods	Orthopedic n=30 Geriatric rehabilitation	81 (67-96) 63	Mobile apps	Providing access to discharge records during transition to home	Usability	—[b]
Bernocchi[52] 2018 Italy	RCT	Multiple diagnoses n=146 Ambulatory	79 (6.5) 84	Video communication in combination with non-eHealth vs usual care	Weekly calls; video communication 2×/month; fall prevention program provided by therapist	Effectiveness, activities (other)	Feasibility, effectiveness, activities, participation
Bernocchi[69] 2016 Italy	Quantitative nonrandomized	Stroke n=15 Ambulatory	71 (11) 47	Video communication in combination with health sensors	Weekly calls with nurse; weekly video communication with physiotherapist	Feasibility (n completed, n sessions)	Effectiveness, body functions, activities
Cannell[44] 2017 Australia	RCT	Stroke n=40 Hospital, rehabilitation unit	74 (10) 37.5	Exergames in combination with virtual reality vs usual care	1 hour/session, 5 days/week, in addition to conventional therapy	Effectiveness, activities (maintaining body position)	Effectiveness, activities
Chan[62] 2012 China	Quantitative nonrandomized	Multiple diagnoses n=90 Geriatric Day hospital	80 (7.1) 73	Exergames vs usual care	10 min/session, 8 sessions total, in addition to conventional therapy	Feasibility (total time spent, average BS[c] and %MHR[d])	Effectiveness, activities
Cimarolli[77] 2017 UnitedStates	Quantitative nonrandomized	Multiple diagnoses n=237 Skilled nurse facility	76 (10.7) 59	Exergames	Recommended use: 2 sessions/ week for 15 min, in addition to conventional therapy	Feasibility (time spent, predictors of intense use)	Effectiveness, external factors

Table 1. Study characteristics. (*continued*)

Author; year; country	Design	Diagnosis; n; setting	Age (SD); female (%)	Intervention	Use of intervention	Primary outcome domain (primary outcome measure)	Secondary outcome domain(s)
Dakin[61] 2011 Australia	Quantitative nonrandomized	Multiple diagnoses n=34 Geriatric rehabilitation	77 47	Health sensors vs usual care	Wore health sensor daily during admission	Effectiveness activities (ADL[e])	Effectiveness, external factors
Da-Silva[57] 2019 UnitedKingdom	RCT	Stroke n=33 Hospital, stroke unit	71 60.6	Health sensors with reminders vs health sensors without reminders	Wore health sensor for 4 weeks, health sensor vibrated to remind patients to use affected arm	Effectiveness, activities (hand and arm use)	Feasibility, adherence
Doornebosch[70] 2007 Netherlands	Quantitative nonrandomized	Stroke n=10 Geriatric rehabilitation	72 (53-94) 80	Robotics	20 minutes/session, 8 sessions total, in addition to conventional therapy	Personal factors (patient's experience)	Effectiveness, body functions
Edmans[68] 2009 UnitedKingdom	Quantitative nonrandomized	Stroke n=13 Hospital, stroke unit	73 23	Virtual reality vs usual care	1 hour/session, 5 days/week	Effectiveness, activities (other)	Effectiveness, activities
Franceschini[56] 2020 Italy	RCT	Stroke n=48 Hospital, rehabilitation unit	72 (64.3) 45.8	Robotics vs usual care	30 minutes/session, 5 days/week over 6 weeks, in addition to conventional therapy	Effectiveness, body functions (muscle power, tone, and reflexes)	Effectiveness, (muscle power, tone, and reflexes)
Gandolfi[71] 2017 Italy	Quantitative nonrandomized	Stroke n=2 Hospital, rehabilitation unit	74 100	Robotics	20 minutes/session, 5 days/week, 10 sessions total, in addition to conventional therapy	Feasibility (compliance, time to set device)	Effectiveness, body functions
Goto[65] 2017 Japan	Quantitative nonrandomized	Orthopedic n=20 Hospital	74 (7.5) 90	Robotics vs usual care	Every other day, in addition to conventional therapy	Effectiveness, body functions (mobility of joints)	Effectiveness, body functions

Table 1. Study characteristics. (*continued*)

Author; year; country	**Design**	**Diagnosis; n; setting**	**Age (SD); female (%)**	**Intervention**	**Use of intervention**	**Primary outcome domain (primary outcome measure)**	**Secondary outcome domain(s)**
Hesse[42] 2014 Germany	RCT	Stroke n=50 Hospital, rehabilitation unit	70 (16) 44	Robotics vs usual care	30 minutes/session, 4 days/week, in addition to conventional therapy	Effectiveness, body functions (muscle power, tone, and reflexes)	Effectiveness, body functions, activities, external factors
Hesse[72] 2010 Germany	Quantitative nonrandomized	Stroke n=1 Not reported	72 0	Robotics	25 minutes/session, 5 days/week, 25 sessions in total, in addition to conventional therapy	Effectiveness, body functions (ADL)	—
Hicks[63] 2016 UnitedStates	Quantitative nonrandomized	Cardiac n=285 Geriatric rehabilitation	79 (48-99) 54.3	Health gateway vs usual care	Encouraged daily use, in addition to conventional therapy	Effectiveness, activities (ADL)	Effectiveness, external factors
Iosa[46] 2015 Italy	RCT	Stroke n=4 Hospital, rehabilitation unit	71.5 (4.51) 50	Exergames in combination with virtual reality vs usual care	30 minutes/session, 3 days/week, in addition to conventional therapy	Feasibility (motivation, time spent, adverse events)	Effectiveness, body functions, activities
Karner[55] 2019 Germany	RCT	Stroke n=56.4% Hospital, rehabilitation unit	73,7 (7.33) 56.4	Robotics vs book reading	30 minutes/session 3 days/week over 3 weeks	Effectiveness, body functions (visual)	—
Koneva[67] 2018 Russia	Quantitative nonrandomized	Stroke n=40 Not reported	84 (1.2) 30	Virtual reality vs usual care	Task-specific training	Effectiveness, body functions (neurological)	Effectiveness, body functions, activities, participation
Laver[50] 2012 Australia	RCT	Multiple diagnoses n=44 Hospital, rehabilitation unit	84.9(4.5) 80	Exergames vs usual care	25 minutes/session, 5 days/week for duration of stay	Effectiveness, activities (mobility)	Effectiveness, body functions, activities, participation

Table 1. Study characteristics. (*continued*)

Author; year; country	Design	Diagnosis; n; setting	Age (SD); female (%)	Intervention	Use of intervention	Primary outcome domain (primary outcome measure)	Secondary outcome domain(s)
Levinger[64] 2016 Italy	Quantitative nonrandomized	Orthopedic n=4 Hospital, rehabilitation unit	70 76	Exergames vs usual care	2 sessions/week, in addition to conventional therapy	Effectiveness, activities (mobility)	Effectiveness, body functions, activities, participation
Li[54] 2020 HongKong	RCT	Orthopedic n=31 Ambulatory	79,3 (9.1) 80.6	Mobile apps vs usual care	Use of app based on rehabilitation goals, in addition to conventional therapy	Effectiveness, activities (mobility)	Effectiveness, feasibility, body functions, activities,
Ling[58] 2017 Netherlands	Mixed methods	Orthopedic n=7 Geriatric rehabilitation	70 (8) 71	Exergames	30 minutes/session, in addition to conventional therapy	Usability (ease of use)	—
Marschollek[75] 2014 Germany	Quantitative nonrandomized	Orthopedic n=14 Ambulatory	83.5 (71-90)	Health sensors	Sensors placed at home for monitoring ADL	Feasibility (installation time, downtimes)	Acceptability
Oesch[49] 2017 Switzerland	RCT	Multiple diagnoses n =54 Geriatric rehabilitation	74 (67-79) 45	Exergames vs self-regulated exercises	30 minutes/session, twice a day	Effectiveness (personal factors)	Effectiveness personal factors, activities
Peel[40] 2016 Australia	RCT	Multiple diagnoses n=270 Geriatric rehabilitation	81 (8) 58	Health sensors with goal-setting vs health sensors without goal-setting	Daily feedback and goal-setting by therapists, in addition to conventional therapy	Effectiveness, activities (mobility)	Effectiveness, activities, participation, external factors
Peel[78] 2011 Australia	Quantitative nonrandomized	Multiple diagnoses n=0 Ambulatory	—	Video communication	All communication conducted through intervention	Feasibility	—

Table 1. Study characteristics. (*continued*)

Author; year; country	Design	Diagnosis; n; setting	Age (SD); female (%)	Intervention	Use of intervention	Primary outcome domain (primary outcome measure)	Secondary outcome domain(s)
Piqueras[47] 2013 Spain	RCT	Orthopedic n=142 Ambulatory	73.3 (6.5) 72.4	Video communication in combination with health sensors vs usual care	1 hour/session over 10 days	Effectiveness, body functions (mobility of joints)	Effectiveness, body functions, activities
Pol[48] 2019 Netherlands	RCT	Orthopedic n=240 Ambulatory	83 (6.9) 79.6	Health sensors in combination with non-eHealth intervention vs non-eHealth intervention vs usual care	Sensors placed at home for monitoring ADL, 4 home visits and 4 telephone consultations	Effectiveness, activities (other)	Effectiveness, participation
Sampson[73] 2012 NewZealand	Quantitative nonrandomized	Stroke n=1 Rehabilitation center	76 100	Robotics in combination with virtual reality	45 minutes/session, 4 sessions/week over 6 weeks, in addition to conventional therapy	Effectiveness, body functions (muscle power, tone, and reflexes)	Effectiveness body functions
Schoone[45] 2011 Netherlands	RCT	Stroke n=24 Geriatric rehabilitation	71.3 (8.2) 33	Robotics	10-30 minutes/sessions, 3 sessions/week over 6 weeks, in addition to conventional therapy	Effectiveness, body functions, activities (hand and arm use)	Effectiveness participation, external factors
Schwickert[74] 2011 Germany	Quantitative nonrandomized	Orthopedic n=8 Geriatric rehabilitation	79.5 50	Robotics, virtual reality	30-45 minutes/session, 2-3 sessions/week for 2-4 weeks, in addition to conventional therapy	Feasibility (adherence, satisfaction)	Effectiveness, body functions, activities, participation
Takano[79] 2020 Japan	Quantitative nonrandomized	Orthopedic n=27 Hospital, rehabilitation unit	81 (6.3) 89	Robotics in combination with exergames	20 min/session 6 sessions/week for 2 weeks in addition to conventional therapy	Effectiveness activities (mobility)	Effectiveness, activities,

Table 1. Study characteristics. (*continued*)

Author; year; country	Design	Diagnosis; n; setting	Age (SD); female (%)	Intervention	Use of intervention	Primary outcome domain (primary outcome measure)	Secondary outcome domain(s)
Taveggia[43] 2016 Italy	RCT	Stroke n=28 Hospital, rehabilitation unit	72 (6) 39	Robotics vs usual care	30 minutes/session, 5 sessions/ week over 5 weeks, in addition to conventional therapy	Effectiveness, activities (mobility)	Effectiveness, activities, participation
Tousignant[76] 2006 Canada	Quantitative nonrandomized	Multiple diagnoses n=4 Ambulatory	70,75 50	Video communication	1 hour/session, 3 sessions/week over 4 weeks	Effectiveness, activities (ADL)	Effectiveness, body functions, activities
VandenBerg[51] 2015 Australia	RCT	Multiple diagnoses n=58 Hospital, rehabilitation unit	80 (12) 62	Exergames vs usual care	1 hour/session, 5 session/week, in addition to conventional therapy	Effectiveness, activities (mobility)	Usability; Effectiveness, activities, participation
Vanoglio[41] 2017 Italy	RCT	Stroke n= 30 Hospital, rehabilitation unit	71 (12) 53	Robotics vs usual care	40 minutes/session, 5 sessions/week over 6 weeks	Feasibility (n completed, adverse events, difficulty)	Effectiveness, body functions, external factors
White[60] 2015 Australia	Qualitative	Stroke N=12 Rehabilitation center, ambulatory	73 (53-83) 33	Mobile apps	Therapist installed apps; patients encouraged to explore iPad	Usability	—
Yoshikawa[66] 2018 Japan	Quantitative nonrandomized	Orthopedic n=19 Hospital	76 (6.85) 81	Robotics vs usual care	14 minutes/session, 12-14 session in 4 weeks, in addition to conventional therapy	Effectiveness, activities (mobility)	Effectiveness, body functions

[a] RCT: randomized controlled trial.

[b] Not available.

[c] BS: Borg Perceived Exertion Scale.

[d] %MHR: maximum heart rate.

[e] ADL: activities of daily living.

Of 40 studies, 17 (43%) included participants who were diagnosed with stroke[41-46,55-57,60,67-73], 10 (25%) included participants with multiple diagnoses[40,49-52,59,61,62-76,78], 11 (28%) included participants with orthopedic problems[47,48,54,58,59,64-66,74,75,79], and 2 studies (5%) included participants with cardiac-related diagnoses[53,63]. Across all studies, the included sample size ranged from 1 to 285 participants.

Various types of eHealth interventions were used. Of 40 studies, 11 studies (28%) delivered the intervention via robotics[41-43,45,55,56,65,66,70-72], 2 studies (5%) combined robotics with virtual reality[73,74], and 1 study (3%) combined robotics with exergames[79]. Additionally, 9 studies (of 40, 23%) investigated exergames[44,46,49-51,58,62,64,77], of which 2 (of 9, 22%) combined exergames with virtual reality[44,46] and 1 (of 9, 11%) combined exergames with health sensors[51]. Of 40 studies, 2 (5%) examined video communication[76,78], 3 (8%) combined video communication with health sensors[47,53,69], and 1 (3%) combined video communication with a non-eHealth intervention[52]. Of 40 studies, health sensors were used in 6 studies (15%)[40,48,57,61,63,75], including 1 (of 6, 17%) in combination with a health gateway[63] and 1 (of 6, 17%) in combination with a non-eHealth intervention[48]. Of 40 studies, 3 studies (8%) investigated mobile apps[54,59,60], and 2 studies (5%) examined virtual reality[67,68].

Outcome measures related to effectiveness were reported in 24 of 40 studies (60 %)[40,42-45,47-50,53,55,56,61,63-68,70,72,73,75,79], and 10 of 40 studies (25%) included outcome measures related to effectiveness and feasibility[41,46,52,54,57,62,69,71,74,77]. Of 40 studies, 2 studies (5%) included outcomes related to usability[58,60], 2 studies (5%) included outcomes related only to feasibility[75,78], 1 study (3%) included outcomes related to effectiveness and usability[51], and 1 study (3%) included outcomes related to feasibility and usability[59]. A detailed description of all included studies can be found in Multimedia Appendix 3.

Study Quality

Results of the quality assessment are presented in Figure 2 and Figure 3. The quality of the included studies ranged from −3 to 5 (on a scale ranging from −5 to 5). The mean overall score was 3 for randomized controlled trails, 1 for quantitative nonrandomized studies, 1 for a mixed methods studies, and 5 for a qualitative study (based on 1 study). In quantitative nonrandomized studies, the most frequent shortcoming was insufficient reporting of confounders; only 2 of 19 studies (11%) accounted for confounders in design and analysis[73,79]. The representativeness of the target population in quantitative nonrandomized studies was also often insufficient; 9 of the 19 studies (47%) reported insufficient information, lacking either adequate explanation of why certain eligible participants chose not to participate or a clear description of the target population[53,61,65,67,69,71,75,76,78]. Additionally, 6 of the 19 studies (32%) included a sample size of less than[64,66,70,72-74].

Table 2. Quality Appraisal of Included Studies

Randomized controlled trails studies	Randomization appropriately performed?	Groups comparable?	Complete outcome data?	Assessors blinded?	Adhere to intervention?	Overal score
Vanoglio, et al (2017) [41]	🙂	🙂	🙂	🙂	🙂	5
Hesse, et al (2014) [42]	🙂	🙂	🙂	🙁	🙂	3
Taveggia, et al (2016) [43]	🙂	🙂	🙂	🙂	😐	4
Cannell, et al (2018) [44]	🙂	🙂	🙂	🙂	🙂	5
Schoone, et al (2011) [45]	🙂	🙂	🙁	🙂	😐	2
Piqueras, et al (2013) [47]	🙂	🙁	🙁	🙂	😐	0
Pol, et al (2019) [48]	🙂	🙂	🙁	🙁	🙁	-1
Oesch, et al (2017) [49]	🙂	🙂	🙂	🙁	🙂	3
Peel, et al (2016) [40]	🙂	🙂	🙂	🙁	🙂	3
Laver, et al (2012) [50]	🙂	😐	🙂	🙂	🙂	4
Berg, et al (2016) [51]	🙂	🙂	🙂	🙂	🙂	5
Iosa, et al (2010) [46]	🙁	🙂	🙁	🙂	🙂	1
Barnason, et al (2009) [53]	😐	🙂	😐	😐	😐	1
Bernocchi, et al (2018) [52]	🙂	🙂	🙂	🙂	🙂	5
Franceschini, et al (2019) [56]	😐	🙂	🙂	🙂	😐	3
Li, et al (2020) [54]	😐	🙁	🙂	🙂	🙂	2
Karner, et al (2019) [55]	🙁	🙂	🙂	🙁	🙂	1
Da-Silva, et al (2019) [57]	🙂	😐	🙁	🙂	🙂	2

Score Calculation

🙂 = +1 😐 = 0 🙁 = -1

Quantitative nonrandomized studies	Representative of the target population?	Are the measurements appropriate?	Complete outcome data?	Confounders accounted for?	Intervention administered as intended?	Overall score
Edmans, et al (2009) [68]	🙂	🙂	😐	😐	🙂	3
Koneva, et al (2018) [67]	😐	🙂	😐	☹	😐	0
Yoshikawa, et al (2018) [66]	☹	🙂	🙂	☹	🙂	1
Goto, et al (2017) [65]	😐	🙂	😐	☹	😐	0
Levinger, et al (2016) [64]	☹	🙂	🙂	☹	🙂	1
Hicks, et al (2016) [63]	🙂	🙂	🙂	☹	😐	2
Chan, et al (2012) [62]	🙂	🙂	🙂	☹	🙂	3
Dakin, et al (2011) [61]	😐	🙂	🙂	☹	🙂	1
Bernocchi, et al (2016) [69]	😐	🙂	🙂	☹	🙂	2
Doornebosch,(2007) [70]	☹	☹	😐	☹	😐	-3
Gandolfi, et al (2017) [71]	😐	🙂	🙂	☹	🙂	2
Hesse, et al (2010) [72]	☹	☹	🙂	☹	😐	-2
Sampson, et al (2012) [73]	☹	🙂	🙂	🙂	😐	2
Schwickert, et al (2011) [74]	☹	🙂	🙂	☹	🙂	2
Marschollek, (2014) [75]	😐	🙂	🙂	☹	🙂	2
Tousignant, et al (2006) [76]	😐	🙂	🙂	☹	🙂	2
Cimarolli, et al (2017) [77]	🙂	🙂	😐	☹	😐	1
Peel, et al (2011) [78]	😐	😐	☹	😐	😐	-1
Takano, et al (2020) [79]	🙂	🙂	🙂	🙂	🙂	5
Qualitative studies	Qualitative approach appropriate?	Data collection methods adequate?	Findings adequately derived from the data?	Results interpreted sufficiently by data?	Coherence in data, analysis, and interpretation?	Overall score
White, et al (2015) 60	🙂	🙂	🙂	🙂	🙂	5
Mixed methods studies	Adequate rationale for mixed methods design?	Different components integrated?	Integration of qualitative and quantitative?	Divergences or inconsistencies addressed?	Components of study adhere to quality criteria?	Overall score
Ling, Y, et al (2017) [58]	🙂	☹	🙂	🙂	☹	1
Backman, et al (2020) [59]	🙂	☹	😐	🙂	☹	0

Score Calculation

🙂 = +1 😐 = 0 ☹ = -1

Effectiveness

Main Results for Effectiveness

Across all studies with a control group (n=27; 27/40, 68%), 73 different outcome measures were reported that were related to effectiveness, including 16 (22%) within the ICF domain "body functions," 40 (55%) in the domain "activities," 11 (15%) in the domain "participation," 4 (5%) in the domain "external factors," and 2 (3%) in the domain "personal factors" (Figure 4). In 15 studies (of 27, 56%), eHealth interventions were found to be at least as effective as non-eHealth interventions when focusing on the primary outcome measure, and 11 studies (of 27, 41%) reported eHealth interventions to be more effective than non-eHealth interventions. Of 27 studies, 1 study (4%) reported beneficial outcomes in favor of the non-eHealth interventions. Results for each ICF domain are described in detail below. A harvest plot illustrating the evidence regarding effectiveness is presented in Figure 5.

Body Functions

Of 40 total studies, 14 studies (35%) included 16 outcomes related to body functions[41,42,45-47,50,54-57,64-67]. Of these 14 studies, 9 studies (64%) found, in 7 outcome measures, significant improvements in favor of the intervention group (Figure 5)[41,46,47,54-56,65-67]. Of 14 studies, 4 studies (29%) reported improved muscle power through robotics[56,65], exergames[46], or mobile apps[54]. Of 14 studies, 4 studies (29%) found that the addition of robotics[56,65,66] or video communication in combination with health sensors[47] improved the mobility of joints when compared with physical therapy alone. Another 2 studies (of 14, 14%) reported that the use of robotics could decrease pain when compared with conventional physiotherapy[65,66]. Koneva and colleagues[67] reported that the use of virtual reality improved neurological status, as measured by the National Institutes of Health stroke scale, when compared with usual care (5.2±0.4 vs 6.3±0.5; $P<.001$).

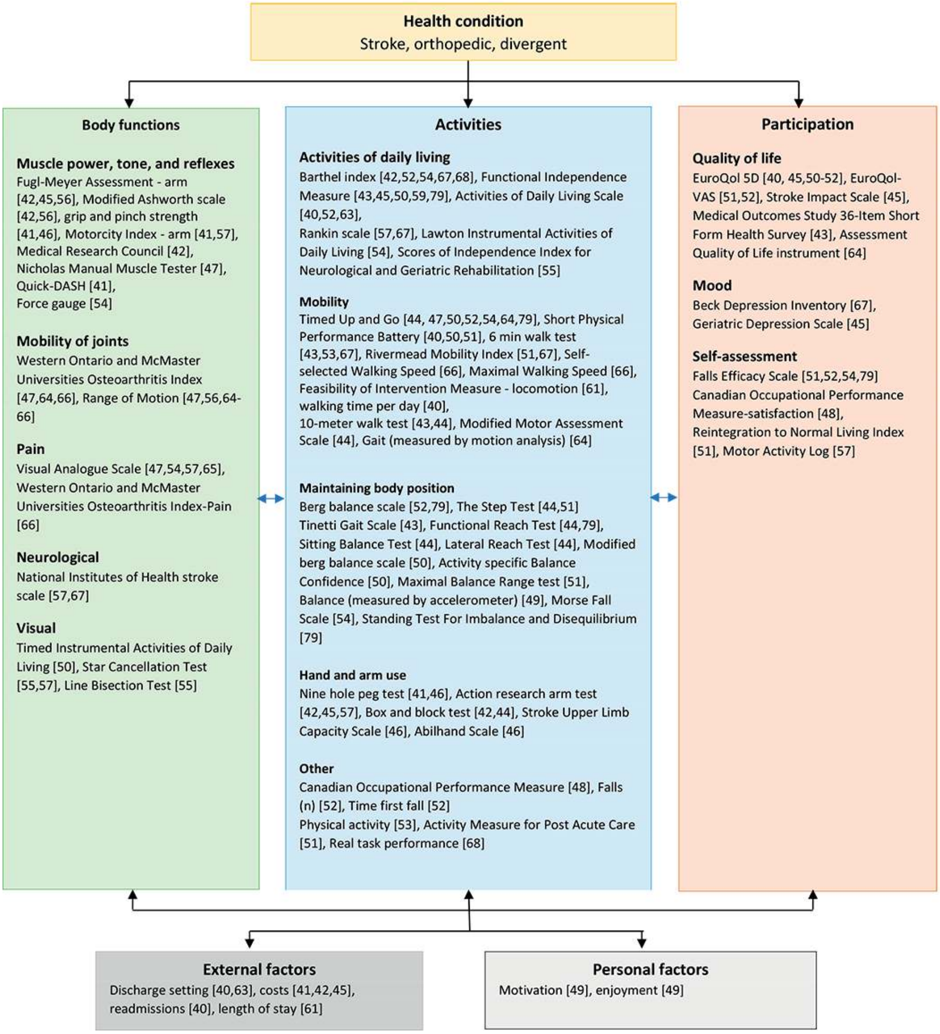

Figure 2. Outcome measures classified on ICF-model

Activities

Of all 40 included studies, 25 studies (63%) reported 40 outcomes related to activities[40-55,57,61-64,66-68,79], and 13 studies (33%) found, in 17 outcomes, a significant outcome in favor of the intervention group[40,41,46,48,50-53,62,63,66,67,79]. Of 40 studies, 5 studies (13%) demonstrated that eHealth was effective in improving activities of daily living when the intervention was delivered via video communication in combination with health sensors and a non-eHealth intervention[52] or when the intervention was delivered via health sensors in combination with health gateways[63], exergames[62], robotics[79], or virtual reality[67]. In these studies, eHealth was compared with usual care[52,67], physiotherapy[62,79], or no intervention[63]. Another 6 studies (of 40, 15%) found that eHealth could contribute to improved mobility through the use of robotics[52,79,] exergames[50], virtual reality[67], video communication in combination with health sensors [52], or health sensors in combination with goal setting[40]. These interventions were compared with physiotherapy[50,41,79], usual care[52,67], or health sensors without goal setting[40]. Of 40 studies, 4 studies (10%) reported improvements in balance when the intervention was delivered via robotics[79], exergames[50], exergames in combination with health sensors[51] or video communication in combination with health sensors[52], when compared with physiotherapy[50,51,79] or usual care[52]. Another 2 studies (of 40, 5%) reported that either robotics[41] or exergames in combination with health sensors[46] could improve hand and arm function when compared with physiotherapy [41] or no intervention[46]. Pol and colleagues[48] found that patient-reported daily functioning significantly improved with the use of health sensors in combination with cognitive behavioral treatment, compared with cognitive behavioral treatment alone, reporting a difference of 1.17 (95% CI 0.47-1.87; $P<.001$). Bernocchi and colleagues[52] reported that the use of video communication in combination with health sensors and a non-eHealth intervention was effective in preventing falls in patients who were at high risk of falling, when compared with usual care (29 falls vs 56 falls; $P<.001$). Of 40 studies, 1 study (3%) demonstrated that the use of video communication in combination with health sensors improved physical activity when compared with usual care[53].

Participation

Of 40 studies, 12 studies (30%) included 11 outcome measures within the participation domain[40,43,45,48,50-53,57,64,67,79]. Of these 11 studies, 3 studies (27%) reported a significant difference in quality of life[52], mood[67], or self-assessment[48] when the intervention was delivered via the use of video communication in combination with health sensors and a non-eHealth intervention[52], virtual reality[67], or the use of health sensors in combination with a non-eHealth intervention[48]. Particularly, Bernocchi and colleagues[52] demonstrated that the use of video communication in combination with health sensors and a non-eHealth intervention significantly improved scores on the EuroQol Visual Analog Scale at 6 months, when compared with usual care (mean 63.8 vs mean 53.5; $P<.001$). Koneva and colleagues [67] reported that the use of virtual reality decreased the severity of depression as measured by the Beck Depression Inventory, when compared with usual care (mean 9.5, SD 5.52 vs mean 10.3, SD 6.03; $P<.05$). Additionally, Pol and colleagues[48] found that the use of health sensors in combination with a non-eHealth intervention significantly improved the performance satisfaction in daily functioning at 6 months, when compared with usual care, reporting a difference of 0.94 (95% CI 0.37-1.52; $P<.001$).

External Factors

Across all 40 studies, 5 studies (13%) included outcome measures related to external factors [40,42,45,61,63]. Of these 5 studies, 2 studies (40%) included robotics as interventions and found significant differences in cost, in favor of the intervention group[41,42]. Of the 5 studies, 1 study (20%) included robotics as an intervention and found a difference in favor of the control group[45]. Hesse and colleagues[42] and Vanoglio and colleagues[41] reported decreases in cost with the use of robotics in comparison with either regular arm therapy (€4.15 [US $4.92] for robotic interventions vs €10.00 [US $11.85] for regular arm therapy, for each patient per session)[42] or physiotherapy (€237 [US $280.73] for robotic intervention vs €480 [US $568.57] for physiotherapy, for each patient per 30 days)[41]. In contrast, Schoone and colleagues[45] reported an increase in total costs when compared with physiotherapy (€644.14 [US $762.99] for robotic interventions vs €423.74 [US $501.93] for physiotherapy). Across all studies, no differences were found with regard to discharge settings[40,63,] readmissions[40], or lengths of stay[61].

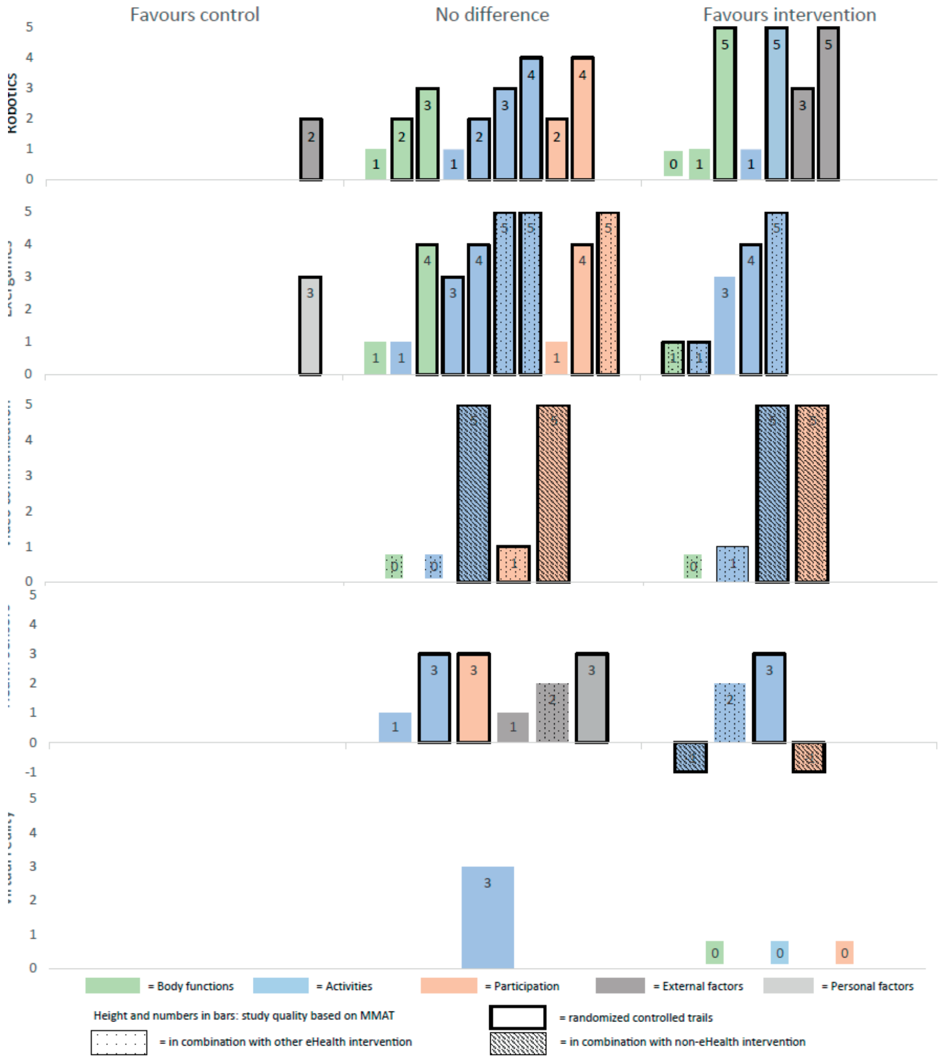

Figure 3. Harvest plot: Effectiveness of eHealth interventions

Personal Factors

Oesch and colleagues[49] found that self-regulated exercise using instruction leaflets was superior to exergames in terms of enjoyment (effect size: 0.88, range 0.32-1.44; *P*<.001) and motivation (effect size: 0.59, range 0.05-1.14; *P*=.046).

Feasibility

Main Results for Feasibility

Of the 40 included studies, 20 studies (50%) evaluated the feasibility of the eHealth intervention used[41,46,50-52,54,57,59,60,62,64,65,69,71,72,74-78], of which 19 (of 20, 95%) concluded that the eHealth intervention was feasible when it was delivered via robotics[41,65,71,72], robotics in combination with exergames[74], exergames[50,62,64,77], exergames in combination with health sensors[46,51], video communication[76], video communication in combination with health sensors[52,69], health sensors[57], health gateways in combination with health sensors[75], or mobile apps[54,59,60]. Peel and colleagues[78] reported that the use of video communication was not feasible due to problems related to patient limitations, staff issues, and the logistics of the system.

The outcome measures applied to evaluate feasibility varied considerably among studies, and a total of 19 different outcome measures were used. Of the 20 studies that reported feasibility, 6 studies (30%) reported outcomes related to "adverse events," 7 studies (35%) reported outcomes related to "adherence," and 7 studies (35%) reported outcomes related to "exclusion rate." Another 4 studies (of 20, 20%) did not specify the outcome measure used to evaluate feasibility but used outcomes related to effectiveness to establish feasibility[54,64,65,72].

Adverse Events

None of the included studies reported serious adverse events during the study period[41,46,50,51,74,76]. However, 2 studies (of 40, 5%) reported that some participants experienced discomfort during exergames [49,50].

Adherence

Of 40 studies, adherence was reported in 7 studies (18%)[49-52,57,74], and 5 studies (13%) reported information regarding the number of completed sessions[41,50-52,69]. Of the 7 studies reporting adherence, 5 studies (71%) reported high levels of adherence, ranging from 76%[52] to 100%[74]. Of the 7 studies, 2 studies (29%) reported low adherence in patients assigned to an exergame intervention when compared with either a non-eHealth intervention[49] or use of the exergame intervention below the recommended level (<30 minutes per week)[77].

Exclusion Rate

Of 40 studies, high exclusion rates were found in 7 studies (18%). Specifically, of these 7 studies, 1 study (14%) reported an exclusion rate of 64%[47], 2 studies (29%) reported an exclusion rate of 75%[49,51], and 4 studies (57%) reported an exclusion rate over 80%[42,45,50,68].

In these latter studies, eHealth was delivered through complex eHealth interventions: robotics[42,45], exergames[50], and virtual reality[68]. The most commonly reported reasons for exclusion were cognitive impairment[45,47,49,51], physical impairment[45,49], and refusal to participate[42,47,49-51,68]. Of these 7 studies, in 2 studies (29%), the reason given for declining to participate was "no interest" in eHealth[50,51].

Usability

Main Results for Usability

Of 40 studies, outcomes related to the usability of eHealth interventions were addressed in 4 studies (10%): 2 studies (5%) evaluated the usability of exergames[51,58,] and another 2 studies (5%) evaluated mobile apps[59,60]. Evaluation of usability consisted of a system usability scale[51,] a survey of patients and therapists[58,59], or semistructured interviews[59,60]. Of the 4 studies that reported usability, 2 studies (50%) included outcomes related to the barrier "cognition," 4 studies (100%) included outcomes related to the aging barrier "motivation," and 1 study (25%) included outcomes related to the barrier "physical ability." None of the studies included outcomes related to the barrier "perception."

Cognition

Ling and colleagues[58] reported that some patients found exergames too complicated because of the requirement to engage in multiple activities simultaneously, and they experienced difficulties in following instructions. To tailor the exergames to older patients with cognitive impairments, the authors advised to minimize the amount of information presented on the screen, which might help older patients to perceive the information better[58]. Additionally, White and colleagues[60] reported that patients with cognitive impairments experienced difficulties in operating mobile apps and needed their partner for support.

Motivation

Van den Berg and colleagues[51] reported a mean score of 62 (SD 21), on the system usability scale (scores ranging from 0 to 100), indicating that participants were generally comfortable with exergames and that they would like to use exergames more frequently. Similar findings were reported by Ling and colleagues[58], who concluded that patients and therapists both found exergames easy to use and therapists intended to use the exergame in the future. Therapists rated the exergame as highly satisfactory for motor rehabilitation in older patients after hip surgery. Findings regarding mobile apps indicated that patients readily grasped the skills required for use and that this was a beneficial source of extrinsic motivation[59,60].

Physical Ability

Ling and colleagues[58] reported that some patients with physical disabilities had difficulties playing certain exergames that required stepping exercises because these patients were unable to maintain balance during exergames.

DISCUSSION

Principal Findings

This review aimed to provide an overview of the effectiveness, feasibility, and usability of eHealth in geriatric rehabilitation. The review included 40 studies that applied eHealth interventions in older patients receiving geriatric rehabilitation. The majority of the included studies showed that eHealth interventions in geriatric rehabilitation are at least as effective as non-eHealth interventions. All studies that delivered eHealth in combination with another non-eHealth intervention reported positive outcomes. Most studies included outcome measures related to the ICF domain "activities." Very few studies included outcomes related to the ICF domain "participation." eHealth seems to be feasible in geriatric rehabilitation, since no serious adverse events were reported and most studies reported high levels of adherence. However, high exclusion rates were found in some studies. Results related to usability indicate that there are certain age-related barriers, such as cognition and physical ability, that lead to difficulties in using eHealth. Very few studies included outcomes related to feasibility and usability. However, these are important prerequisites to maximize the likelihood of successful implementation, and they thereby influence the effectiveness of eHealth.

Comparison With Prior Work

Our findings suggest that eHealth delivered via robotics, exergames, or health sensors is often found to be at least as effective as non-eHealth. Previous reviews that examined robotics[80], exergames[16], or health sensors[81,82] often found more beneficial results in favor of the intervention group. These reviews did not focus on older adults who were admitted for geriatric rehabilitation, and this could indicate that there are certain age-related barriers that affect the effectiveness of eHealth in older adults receiving geriatric rehabilitation. All of the included studies that delivered eHealth in combination with a non-eHealth intervention reported beneficial outcomes in favor of the intervention group. This is in line with other studies in which eHealth was delivered in combination with a non-eHealth intervention[83-85]. This indicates that eHealth is more beneficial when provided through blended care, where eHealth is delivered in combination with face-to-face treatment. This may provide a better quality of care by combining the best of the two types of interventions. This seems to especially be the case when blended care is delivered via video communication[52] or health sensors[48], since it offers the possibility to monitor and treat patients remotely.

Almost all of the studies that included outcomes related to feasibility concluded that eHealth was feasible in older adults receiving geriatric rehabilitation. None of the studies reported serious adverse events, which is in line with other reviews concerning feasibility of exergames[15,86]. The majority of the studies that included outcomes related to adherence or completed sessions reported high levels of adherence. Previous reviews that examined exergames also reported high adherence rates[86]. Some studies where eHealth was delivered via robotics or exergames reported a high exclusion rate (up to 88%). All studies with exclusion rates of ≥75% were conducted in a geriatric rehabilitation setting[45,49] or in a hospital with a dedicated rehabilitation unit[50,51]. Reasons for exclusion were mostly cognitive or physical impairments, problems that are often present in older patients receiving geriatric rehabilitation. These findings indicate that eHealth in geriatric rehabilitation is safe to use and overall adherence is expected to be high, but complex eHealth interventions such as robotics and exergames might only be feasible in a selective group of older patients receiving geriatric rehabilitation.

There is limited available evidence on the usability of eHealth interventions. The studies included in our review indicate that exergames and mobile apps are usable once older patients have been trained in their use. However, there were certain age-related barriers associated with cognitive or physical ability that led to difficulties in using eHealth. While we did not find studies that reported problems in the use of eHealth due to problems in perception, 2 of 4 studies (50%) that included usability outcome measures explicitly excluded patients with visual impairments[51,58]. This might suggest that poor usability was expected in patients with visual impairments; this is in line with findings from other studies[27]. These findings suggest that usability problems are expected in older patients receiving geriatric rehabilitation, since they often suffer from cognitive, physical, or visual impairments. eHealth should be tailored to these specific age-related barriers to maximize the probability of successful use and implementation[22,27]. Furthermore, most studies did not incorporate clear usability endpoints, and the evaluation of usability varied considerably among studies. The lack of using clear endpoints or reliable and validated questionnaires combined with task metrics (preferably, task completion) to evaluate usability hampers the ability to pinpoint usability issues and prevents comparisons across different eHealth types[25,87].

Strengths and Limitations

The first strength of this review is the extensive search strategy that covered a broad range of search databases and included all types of research designs. Another strength of this review is the categorization of outcome measures based on the ICF model, providing a clear overview of different types of outcome domains evaluated in the included studies. Nonetheless, several limitations of this systematic review should be noted. While this review provides a broad overview of the literature on 3 different concepts, our study design led to a vast variety of different outcome measures related to effectiveness. The inclusion of various outcomes measures, in combination with various eHealth interventions and diagnoses, limited our ability to draw definitive conclusions. Since a meta-analysis was not feasible, we were unable to report an effect size and publication bias. We instead provided an overview of the effectiveness of eHealth interventions using a harvest plot. Lastly, while we used a separate search string that included keywords related to usability, we only found 4 studies that included outcomes on usability. A possible explanation might be that we did not include specific Computer Science search databases, which might include more studies that are related to usability[88]. Furthermore, despite the massive growth in eHealth studies, only a small portion publish their usability results[89].

CONCLUSIONS

In conclusion, eHealth can improve rehabilitation outcomes in older adults receiving geriatric rehabilitation. Based on our findings, comparisons to literature, and the strengths and limitations of our review, our main results and recommendations for further research and the use of eHealth in clinical practice are (1) keep it simple, (2) include evidence on usability, (3) focus on participation, and (4) ensure consensus. First, simple interventions have the most potential to improve rehabilitation outcomes in older adults receiving geriatric rehabilitation, especially, when they are provided as blended care. Additionally, simple eHealth interventions have a higher chance of feasibility in older patients receiving geriatric rehabilitation who often suffer from cognitive or physical impairments. Second, scarce evidence on the usability of eHealth might hamper the implementation of eHealth in older patients receiving geriatric rehabilitation and could negatively influence effectiveness and feasibility. Further research on this topic with clear endpoints is needed. Health care professionals need to be aware of the usability of eHealth interventions they are providing. Third, participation is a key concept in geriatric rehabilitation and plays an important role in enabling older patients to continue living as independently as possible. Future research on eHealth interventions should consider including outcome measures related to participation.

Fourth, current evidence on the use and evaluation of eHealth in geriatric rehabilitation is diverse, making it hard to compare outcomes and draw evident conclusions. Consensus on the use and evaluation of eHealth is needed for further development and implementation of eHealth in geriatric rehabilitation.

AUTHORS' CONTRIBUTIONS

JK screened titles of the identified studies. JK and AV screened the abstracts of all potentially relevant studies and obtained and reviewed the full texts. Disagreements between JK and AV were discussed until a consensus was reached. If a disagreement could not be resolved, EFvDvI was consulted. JK extracted the data. AV also extracted a subset of the data (10% of included studies) to check interrater reliability. JK performed quality assessment, and 10% of the included studies were selected at random and additionally assessed by AV to check interrater reliability. In 12 cases, a third reviewer, EFvDvI, was needed to achieve consensus during the process of study selection.

CONFLICTS OF INTEREST

None declared.

ABBREVIATIONS

ICF: International Classification of Functioning, Disability, and Health.

MMAT: Mixed Methods Appraisal Tool.

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses.

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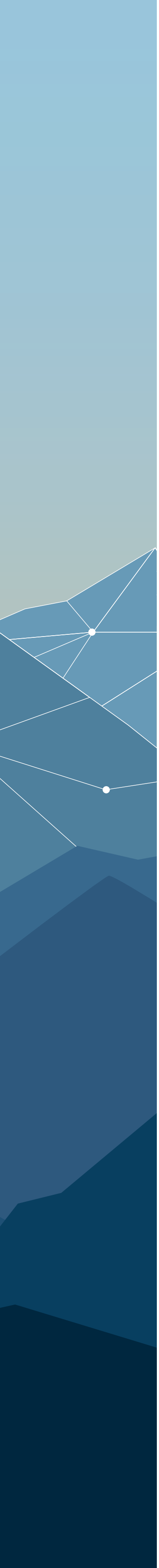

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eHealth in Geriatric Rehabilitation: An International Survey of the Experiences and Needs of Healthcare Professionals.

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ABSTRACT

While eHealth can help improve outcomes for older patients receiving geriatric rehabilitation, the implementation and integration of eHealth is often complex and time-consuming. To use eHealth effectively in geriatric rehabilitation, it is essential to understand the experiences and needs of healthcare professionals. In this international multicentre cross-sectional study, we used a web-based survey to explore the use, benefits, feasibility and usability of eHealth in geriatric rehabilitation settings, together with the needs of working healthcare professionals. Descriptive statistics were used to summarize quantitative findings. The survey was completed by 513 healthcare professionals from 16 countries. Over half had experience with eHealth, although very few (52 of 263 = 20%) integrated eHealth into daily practice. Important barriers to the use or implementation of eHealth included insufficient resources, lack of an organization-wide implementation strategy and lack of knowledge. Professionals felt that eHealth is more complex for patients than for themselves, and also expressed a need for reliable information concerning available eHealth interventions and their applications. While eHealth has clear benefits, important barriers hinder successful implementation and integration into healthcare. Tailored implementation strategies and reliable information on effective eHealth applications are needed to overcome these barriers.

Keywords: geriatric rehabilitation; eHealth; implementation; barriers and facilitators; information needs

INTRODUCTION

With an aging global population and an ever-expanding number of older adults with one or more long-term conditions, the demands placed on geriatric rehabilitation are increasing rapidly[1]. Geriatric rehabilitation has been defined as "a multidimensional approach of diagnostic and therapeutic interventions, the purpose of which is to optimize functional capacity, promote physical activity and preserve functional reserve and social participation in older people with disabling impairments"[2]. Due to a rapidly expanding older population and an increasing lack of staff, new strategies are required to maintain and advance the implementation and delivery of geriatric rehabilitation. Promising solutions such as eHealth may be one way to help overcome these challenges.

One definition of eHealth is "the use of digital information and communication to support and/or improve health and healthcare"[3]. eHealth interventions vary widely, from simple approaches such as video communication, to complex treatment applications involving robotics. A growing body of evidence suggests that eHealth can contribute to improved outcomes for older patients receiving geriatric rehabilitation[4-7]. The COVID-19 pandemic highlighted the need for substantial changes in the delivery of rehabilitation, with reduced capacity, reduced time spent per patient and reduced access to rehabilitation facilities[8, 9]. This emphasizes the importance of eHealth interventions that enable remote monitoring and treatment of patients, enhancing the accessibility and the continuity of rehabilitation. Although the COVID-19 pandemic has accelerated the use of eHealth, the adoption of eHealth is still lagging behind and a number of obstacles hinder the successful development, implementation and integration of eHealth in geriatric rehabilitation[10].

Successful implementation of eHealth involves considerable time and effort and is often complex[11-13]. To facilitate integration into clinical practice, implementation of eHealth may also require changes to a healthcare professional's workflow[14, 15]. Another challenge facing healthcare professionals is the ever-increasing number of eHealth interventions and staying up to date in which eHealth interventions are effective, feasible, usable and suit their specific context[16, 17].

As healthcare professionals are central to the successful application of eHealth, the key to promoting implementation and integration of eHealth in geriatric rehabilitation is a better understanding of the experiences and needs of healthcare professionals. The goal of this study was to provide an overview of the use, benefits, feasibility, usability and needs of healthcare professionals regarding eHealth in geriatric rehabilitation across different countries. This study is part of the EAGER (EheAlth in GEriatric Rehabilitation) research line. The first study consisted of a systematic review of the effectiveness, feasibility and usability of eHealth in geriatric rehabilitation[4].

MATERIALS AND METHODS

Design

An online international multicentre cross-sectional survey study was conducted between December 2021 and April 2022. Results were reported based on the Checklist for Reporting Results of Internet E-Surveys (CHERRIES), a 30-item checklist for web surveys[18].

Study Population and Setting

We included healthcare professionals who were (1) working in a geriatric rehabilitation setting, (2) aged 18 years old and over, (3) understood English and (4) had at least three months experience with the patient population. Healthcare professionals not available during the study period were excluded. Taking into account international variation between different healthcare systems and provision of geriatric rehabilitation[19, 20], we included a range of geriatric rehabilitation settings such as post-acute rehabilitation facilities, acute hospitals, ambulatory settings, geriatric day hospitals, nursing homes, skilled nurse facilities and rehabilitation hotels.

Recruitment and Consent

Eligible healthcare professionals were recruited in geriatric rehabilitation facilities across 16 countries: Australia, Brazil, Canada, Czech Republic, Germany, Ireland, Malta, The Netherlands, New Zealand, Romania, Russia, Singapore, South Korea, Spain, Switzerland and the United Kingdom. Per country, one primary contact person was designated to distribute the survey to the geriatric rehabilitation facilities within that country. All primary contacts were experts in the field of geriatric rehabilitation and/or eHealth and were native speakers. Almost all persons acting as primary contacts were members of the European Geriatric Medical Society's 'Special Interest Group for Geriatric Rehabilitation' and were recruited through this network. Distribution of the survey varied per country, based on the personal preferences and experiences of the primary contact. Distribution variously consisted of email lists, posts to specific professional societies (such as the British Geriatrics Society) and posts on social networks (Twitter and LinkedIn). The survey invitation included a link to the online survey and study information including purpose, expected duration (10 min), voluntariness of participation, confidentiality of responses and contact details of the principal investigator. To increase response rates, in each participating country a reminder was sent two weeks after the initial invitation.

Data Collection

A digital survey was designed based on the experiences of experts in eHealth in geriatric rehabilitation and the results of our previous systematic review on eHealth in geriatric rehabilitation [4]. We designed the first draft in Dutch and piloted it in a national study within the Netherlands. The first draft consisted of a total of 24 questions, four of which were open-ended to obtain detailed information. To improve accuracy and reliability of data analysis, the results of these open-ended questions were indexed and converted into multiple-choice questions. The second draft was then translated into English and sent to our primary contacts in each country for feedback. Based on their suggestions for improvement, the survey was revised with the goal of ensuring an adequate balance between the existing and the revised or new questions. The main changes entailed the phrasing of the questions and questions related to specific eHealth interventions. In the final version of the survey, questions could only be answered by participants who had experience with that type of eHealth intervention. The final survey was then translated into six languages (Czech, German, Portuguese, Romanian, Russian and Spanish) by the primary contact person in the corresponding country. The online survey was hosted by Castor Electronic Data Capture (Castor EDC; Castor, Amsterdam, The Netherlands)[21], a secure, cloud-based electronic data capture platform. The survey had a maximum of 10 questions per page, all of which were mandatory. If a respondent failed to complete a particular question, they were asked to complete it before they moved on to the next section. Respondents could review and edit answers at any time during completion of the survey. No personal information was collected and no participant IP addresses were stored or downloaded.

Measures

The survey was divided into six sections: participant characteristics, use of eHealth, benefits, usability, feasibility and the needs of professionals regarding eHealth in geriatric rehabilitation. Questions in the sections regarding benefits, usability and feasibility only became visible to respondents who indicated that they had used eHealth during their treatments. Respondents who indicated that they had used specific types of eHealth interventions were asked about their experience regarding benefits and usability for each type of eHealth. The final survey consisted of 33 questions. All questions were structured and were multiple-choice or scale questions. The scale questions were formulated as follows: For each type of eHealth intervention, respondents were asked to rate the ease of use for the professional and the patient based on a 5-point Likert scale (1 = very complex to 5 = very easy). Respondents were asked how satisfied they were with the implementation of eHealth in their institution based on a 100-point scale (0 = very dissatisfied to 100 = very satisfied). Lastly, respondents were asked to rate their institution's vision regarding the use of eHealth on a 100-point scale (0 = inadequate to 100 = good).

Statistical Analyses

Descriptive statistics and frequency distributions were used to describe the single-choice and multiple-choice questions. A Pearson product–moment correlation was run to determine the relationship between satisfaction with the implementation of eHealth and the vision of the use of eHealth in the corresponding institution. A one sample t-test was run to determine the difference between mean scores for ease of use of all types of eHealth interventions. A heatmap was created for results related to the benefits of eHealth, with results classified and color-coded from red (0%) to green (100%). Surveys less than 90% complete were excluded from the final data analysis. Data were analyzed with SPSS version 25.0.

Ethical Considerations

This study was approved by the Medical Ethics Review Committee of Leiden–Den Haag–Delft (N20.126.1) and approved by the relevant ethics committee in participating countries as per local requirements. All participants signed the informed e-consent by clicking a dedicated button available in the invitation link, with which they stated that they were aware that participation was voluntary.

RESULTS

Overall, the survey was initialized 794 times, with 513 (65%) participants completing 90% or more of the survey questions. Participant characteristics are presented in Table 1. The majority were from Europe (439 of 513 = 86%), of whom most were from The Netherlands (248 of 513 = 48%) or the Czech Republic (52 of 513 = 10%). The median age of participants was 39 years (IQR 32–49), the median number of years of work experience within geriatric rehabilitation was 8 (IQR 4–15) and 64% (329 of 513) of the respondents were female. Participants mostly worked as physiotherapists (163 of 513 = 33%), medical practitioners/geriatricians (107 of 513 = 22%) or as nurses (82 of 513 = 17%).

Table 1. Sociodemographic and professional characteristics of participants (n = 513)

	n (%)
Sex	
Female	329 (64)
Male	178 (35)
Prefer not to say	5 (1)
Age	
18 – 29	100 (20)
30 – 39	158 (31)
40 – 49	130 (25)
50 – 59	83 (16)
> 60	42 (8)
Profession	
Physiotherapist	163 (33)
Medical practitioner/geriatrician	107 (22)
Nurse	82 (17)
Occupational therapist	61 (13)
Speech therapist	29 (6)
Other	74 (15)
Working years	
0 – 5	171 (33)
6 to 15	218 (43)
16 to 25	92 (18)
> 25	32 (6)
Continent	
Europe (Including the United Kingdom and Ireland)	439 (86)
Asia	50 (10)
North and South America	32 (6)
Oceania	10 (2)
Type of rehabilitation facility	
Post-acute rehabilitation facility	342 (67)
Acute hospital	45 (9)
Ambulatory (home based)	39 (8)
Geriatric day hospital	38 (7)
Other	49 (10)
Experience with eHealth during treatments?	
Yes	263 (51)
No	250 (49)

Profession, other: Nurse practitioner physician assistant, Medical practitioner in training, Psychologist, Dietician, Manager/team leader, Researcher, Social worker. Type of rehabilitation facility, other: Nursing home, skilled nursing facility, rehab hotel

Use of eHealth

Results for the use of eHealth are presented in Table 2. Just over half of the respondents (263 of 513 = 51%) reported using eHealth during their treatments. Of the participants with experience in eHealth during their treatments, only a small proportion (20%) used eHealth daily or almost daily. Overall, only a small percentage of the total number of participants included in this study used eHealth daily or almost daily (52 of 513 = 10%). We also found wide variation between countries in terms of experience with eHealth (ranging from 35% to 94%) and the daily use of eHealth (ranging from 2% to 56%). Of the 263 participants with experience in eHealth, a substantial number had used simple interventions such as mobile apps (153 of 263 = 58%) and video consultations with patients (140 of 263 = 53%). More complex eHealth interventions, such as robotics (42 of 263 = 16%) or virtual reality (36 of 263 = 14%) were used far less often. A little less than half of the participants who responded to questions concerning training in the use of eHealth (78 of 160 = 49%) had received some form of training.

Table 2. Frequency of the use of eHealth (n = 263)

	n (%)
Applied types of eHealth interventions	
Mobile apps	153 (58)
Video consultation with patients	140 (53)
Health-sensors	101 (38)
Exergames	101 (38)
Robotics	42 (16)
Virtual reality	36 (14)
Frequency of use	
Incidental	92 (35)
Weekly	65 (25)
Few times a month	54 (21)
Daily or almost daily	52 (20)
eHealth part of a rehabilitation program	
Yes, right now	143 (51)
Yes, in the past	36 (13)
No	91 (33)
I don’t know	8 (3)

Training received in the use of eHealth (n =160)	
No, I’ve only read the included manual	52 (33)
No	29 (18)
Yes, I received training on how to use eHealth	40 (25)
Yes, I received training on the implementation of eHealth	22 (14)
Yes, I received training on how to tailor eHealth to age-related barriers (e.g. cognitive or physical disabilities)	16 (10)
I don’t know	1 (1)

Benefits

The benefits experienced per form of eHealth are described in Table 3. Most participants who had experience with specific types of eHealth indicated that virtual reality (20 of 26 = 77%), exergames (29 of 50 = 73%) and robotics (28 of 36 = 78%) improved the reha-bilitation environment. These participants also felt that virtual reality (23 of 26 = 64%), ex-ergames (28 of 50 = 70%) and robotics (28 of 36 = 78%) increased patients’ self-management. Almost all participants who had used video consultation for contact with patients (61 of 68 = 90%) indicated that it was beneficial for remote care.

Regarding specific patient benefits, most participants with experience in robotics (23 of 36 = 64%) indicated that it helped a faster recovery. Of the participants with experience in video consultations, 68% (46 of 68) indicated that it contributed to increasing the fre-quency of treatment. Similarly, of the participants with experience in exergames, 62% (25 of 40) stated that it increased patients’ confidence, while 62% (29 of 47) of participants with experience in health sensors perceived increased self-direction amongst patients during treatment. Participants also indicated that virtual reality (19 of 26 = 79%), exer-games (36 of 40 = 90%) and robotics (25 of 36 = 69%) offered the patient a more entertaining form of therapy.

Table 3. Heatmap of benefits per form of eHealth.

	Mobile Apps N = 75	Health Sensors N = 47	Virtual Reality N = 26	Exer-games N = 40	Video Con-sultation N = 68	Robot-ics N = 36
Types of benefits experienced						
Ease of use	24 (32%)	18 (38%)	6 (23%)	10 (25%)	26 (38%)	9 (25%)
Better quality treatment	36 (47%)	23 (49%)	6 (23%)	10 (25%)	30 (44%)	7 (9%)
Improvement of the rehabilitation environment	23 (30%)	17 (36%)	20 (77%)	29 (73%)	18 (26%)	28 (78%)
Increasing self-management of the patient	21 (28%)	14 (30%)	18 (69%)	28 (70%)	8 (12%)	23 (64%)
Possibility of remote care	43 (57%)	19 (50%)	6 (23%)	7 (18%)	61 (90%)	2 (18%)
Efficient deployment of staff	37 (49%)	23 (49%)	9 (35%)	17 (43%)	30 (44%)	12 (33%)
Types of benefits for the patient						
Faster recovery	14 (19%)	13 (28%)	13 (54%)	18 (45%)	10 (15%)	23 (64%)
Increase in treatment frequency	39 (52%)	15 (32%)	12 (50%)	18 (45%)	46 (68%)	13 (36%)
More confidence	38 (51%)	26 (55%)	12 (50%)	25 (62%)	25 (37%)	11 (31%)
More self-direction	40 (53%)	29 (62%)	10 (42%)	17 (42%)	32 (47%)	11 (31%)
More fun form of therapy	30 (40%)	15 (32%)	19 (79%)	36 (90%)	15 (22%)	25 (69%)
Types of disadvantages encountered						
It does not meet the needs of the patient well	28 (39%)	14 (30%)	3 (16%)	12 (31%)	26 (40%)	10 (29%)
Applications crash or do not work properly	22 (31%)	11 (24%)	4 (21%)	10 (26%)	25 (39%)	6 (18%)
Difficult to use or apply	30 (42%)	18 (39%)	3 (16%)	16 (31%)	19 (29%)	17 (50%)
None	16 (22%)	14 (30%)	10 (53%)	13 (33%)	16 (25%)	12 (35%)

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Feasibility

Outcomes concerning feasibility are presented in Table 4. Participants who had previously used eHealth were asked about problems they may have encountered during regular use. The most frequently reported problems were (1) insufficient available resources (89 of 136 = 65%), (2) no organization-wide method of working or implementation (69 of 136 = 51%) and (3) costs (58 of 136 = 43%). Participants reported certain risks associated with using eHealth, such as technical problems (105 of 136 = 77%), no supervision (58 of 136 = 43%) and concerns regarding the replacement of physical contact (57 of 136 = 42%). When asked to rate the implementation process of eHealth within their department, participants reported low satisfaction with the implementation of eHealth within their settings (median 40, IQR 4.0–63), while only 11% (15 of 136) indicated they were very satisfied (range 75–100).

Table 4. Results related to feasibility of eHealth (n=136)

	n (%)
Problems encountered in structural use of eHealth	
Insufficient available resources	89 (65)
No organization wide method of working/implementation	69 (51)
Costs	58 (43)
Shortage of professional knowledge	55 (40)
Lack of time	47 (34)
Space shortage	37 (27)
Inappropriate target group	26 (19)
Lack of motivation	20 (15)
Other (adherence, accessibility, lack of effort)	10 (7)
No problems	5 (4)
Patient's skills to use eHealth	
Sufficient cognitive functioning	112 (82)
No problems with vision, hearing or speech	77 (57)
Supervision from caregiver/family	72 (53)
Motivation	67 (49)
Independence	57 (42)
Digital literacy	56 (41)
Sufficient motor functioning	24 (18)

Risks of eHealth	
Technical problems	105 (77)
No supervision	58 (43)
Concerns replacement physical contact	57 (42)
Distress/confusion in patients	53 (39)
Difficult to implement	52 (38)
Reduction in quality of care	39 (29)
Privacy sensitive	31 (23)
Discomfort (i.e. lower back pain, lower limb pain)	22 (16)
Other (no risks, solitude, digital literacy, poor performance exercises)	10 (3)

Usability

The ease of use per type of eHealth intervention is displayed in Figure 1. According to healthcare professionals, patients found virtual reality (median 3, IQR 2–4) and robotics (median 3, IQR 3–4) the most easy-to-use eHealth interventions. For professionals themselves, video consultations (median 4, IQR 3–5) and virtual reality (median 4, IQR 3–5) were the most easy-to-use forms of eHealth. Mobile apps were felt to be the most complex type to use by patients (median 3, IQR 2–4) and as the second most complex by professionals (median 3, IQR 2–3), with professionals rating robotics as the most complex form (median 3, IQR 3–4). With the exception of robotics ($p = 0.208$), professionals found all types of eHealth interventions significantly easier to use compared with patients ($p \leq 0.01$).

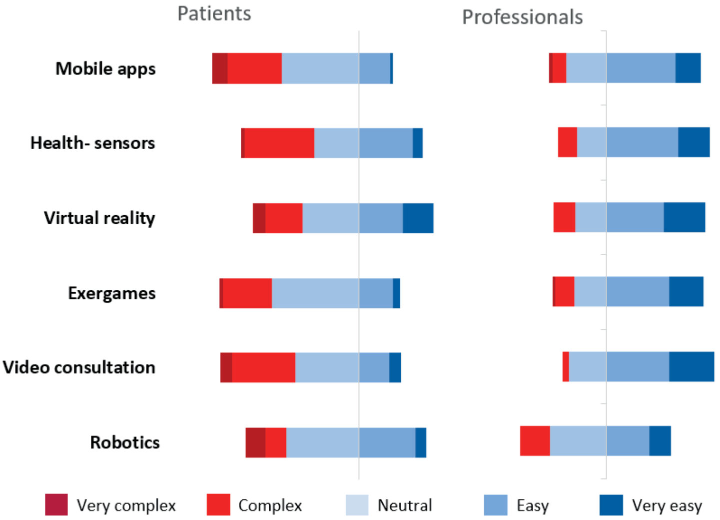

Figure 1. Usability: ease of use per form of eHealth, as perceived by professionals. Distribution of the ease-of-use scales per form of eHealth, ranging from very complex (1) to very easy (5).

Needs

Enabling factors and barriers to the use or implementation of eHealth are presented in Figures 2 and 3. Results for the analysis of professional needs are described in Table 5. The majority of participants indicated that the availability of technical resources (362 of 513 = 71%), digital support during use (278 of 513 = 54%), enthusiasm among colleagues/employers (268 of 513 = 52%) and ease of use (258 of 513 = 50%) were enabling factors that influenced the use or implementation of eHealth. By contrast, lack of knowledge (288 of 513 = 56%), inadequate tailoring to the older population in geriatric rehabilitation (276 of 513 = 54%) and financial issues (268 of 513 = 52%) were considered barriers to the use or implementation of eHealth.

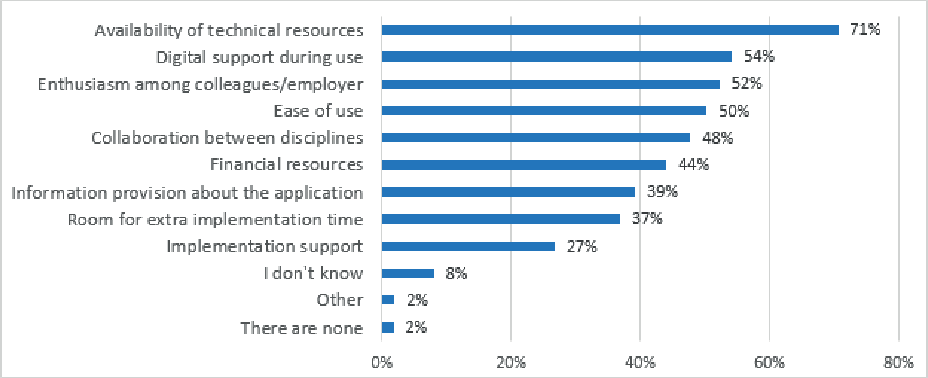

Figure 2. Enabling factors that influence the use or implementation of eHealth (n = 513).

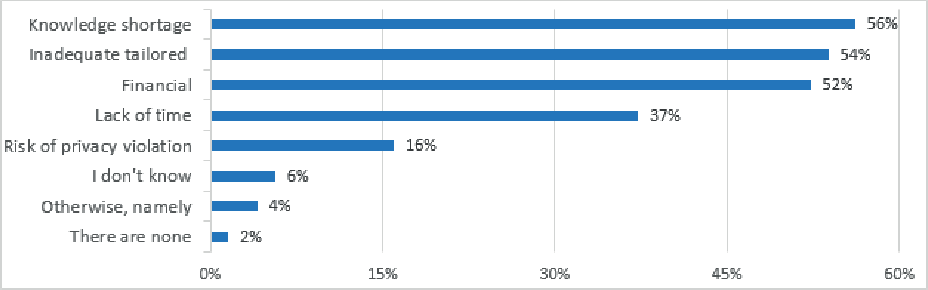

Figure 3. Barriers that influence the use or implementation of eHealth (n = 513).

According to participants, the most important information was related to the types of eHealth available (381 of 513 = 74%), the application or implementation of eHealth (355 of 513 = 69%) and the benefits of eHealth (311 of 513 = 61%). Fifty-eight percent (297 of 513) of participants indicated they would like to increase their use of eHealth. The odds of participants who had experience with eHealth considering making more use of eHealth was 3.135 (95% CI 2.19, 4.47) times compared to participants who did not have any experience with eHealth. Participants rated their institution's vision regarding the use of eHealth as inadequate (median: 25, IQR 3–50) and only 8% (22 of 265) held a positive view of their institution's vision (range 75–100) concerning the use of eHealth. There was a strong correlation between satisfaction with the implementation of eHealth and a clear institutional vision regarding the use of eHealth (r = 0.716, $p \leq 0.01$).

Table 5. Needs of professionals regarding the use of eHealth (n=513)

	n (%)
Information needs concerning eHealth	
Which types of eHealth exist	381 (74)
Applying or implementing eHealth	355 (69)
The benefits of eHealth	311 (61)
The operation of eHealth applications	260 (51)
I don't have any information needs	23 (4)
I don't know	13 (3)
Other (training)	6 (1)
How to receive information about eHealth (n=265)	
Digital course	140 (53)
Course on location	137 (52)
Webinar	129 (49)
Written (article, information letter, manual)	100 (38)
Fact sheet	76 (29)
No preference	18 (7)
Would you like to make more use of eHealth?	
Yes	297 (58)
Maybe	160 (31)
I don't know	41 (8)
No	15 (3)

DISCUSSION

Principal Findings

This international survey provided an overview of the use, benefits, feasibility, usability and needs of healthcare professionals regarding eHealth in geriatric rehabilitation. The survey included 513 professionals working in geriatric rehabilitation facilities across 16 countries. This large study is the first regarding eHealth in this setting. First, while over half of all participating healthcare professionals had experience of eHealth in clinical practice, only a tiny percentage (20%) integrated eHealth into their daily practice. Second, an institution-wide strategy for the use and implementation of eHealth (that includes topics such as the availability of technical resources, digital support and training) is an important enabling factor for the successful use and implementation of eHealth. Third, according to healthcare professionals, patients find eHealth complex to use, especially patients with cognitive impairment. Finally, there is a considerable need among professionals for more information concerning available and effective eHealth interventions, together with how they can be best applied and implemented.

Comparison with Prior Work

Overall, the healthcare professionals involved in this study reported a low daily use of eHealth interventions. To the best of our knowledge (based on literature available in English), this is the first study investigating the use of eHealth in geriatric rehabilitation. Previous studies that examined the use of eHealth in other healthcare settings such as home care[22], inpatient rehabilitation centers[23, 24], or primary care[25-27] reported moderate (43%) to low (13%) use of eHealth. However, the reported use of eHealth varied greatly, dependent on the publication date, type of eHealth and countries included. Furthermore, the frequency of use was not reported. Variation between countries can potentially be explained by factors ranging from the healthcare professional's personal characteristics such as attitudes toward digital technology, personal experience with eHealth interventions, trust in eHealth interventions or demographics[26-28], to regional factors such as readiness of a healthcare system, as well as policy and cultural differences[29].

Although daily use of eHealth was low, most respondents expressed a willingness to increase their use. Our results identified several barriers to increasing the structured use of eHealth in geriatric rehabilitation, including insufficient availability of resources, the lack of an organization-wide implementation strategy and a lack of knowledge. Similar barriers, including a limited knowledge of eHealth, lack of resources and the lack of integration into the daily workflow, have been reported in earlier studies[13, 30, 31]. Conversely, an institution-wide strategy that includes topics such as the availability of technical resources and digital support for the use of eHealth are important enabling factors that increase the structured use of eHealth. Earlier reviews that examined barriers and facilitators influencing the implementation and integration of eHealth arrived at similar conclusions[13, 22, 30, 32, 33], with regularly identified facilitators including ease of use, leadership engagement and adaptability of eHealth[13, 30, 31]. Although these earlier studies were not conducted in a geriatric rehabilitation setting, the commonality of results suggests that barriers and facilitators influencing implementation and integration of eHealth are likely generalizable across different healthcare settings. However, these studies also noted that barriers are dynamic and likely to change over time[30]. Finally, while the COVID-19 pandemic accelerated the use of eHealth, healthcare systems still face challenges when attempting to adopt eHealth, primarily due to difficulty in adjusting workflows and a funding system geared to delivering face-to-face care[10].

According to the professionals participating in our study, their patients find eHealth complex to use, although this varied considerably depending on the eHealth intervention and professionals might underestimate patients' capabilities. Age-related impairments such as the cognitive, physical and visual limitations that are common in older adults can greatly influence one's ability to effectively use eHealth interventions[34-37]. Furthermore, in a recent review, we identified studies with exclusion rates of up to 80%, with cognitive impairment as the most commonly reported reason for exclusion[4]. This is in line with our present findings, since adequate cognitive functioning as well as adequate vision, hearing or speech are all frequently reported requirements if patients are to make effective use of eHealth. Of the available eHealth interventions, patients find mobile apps the most complex type according to healthcare professionals. Although mobile apps are usually widely available and easily downloadable from an app store, few apps have been developed using a co-creation process or fewer still are sufficiently tailored to the age-related impairments of an older adult receiving geriatric rehabilitation[33, 38]. Finally, while healthcare professionals viewed eHealth as complex for patients, the complexity for healthcare professionals should not be underestimated. Ease of use is the most frequently cited factor underlying successful use of eHealth by healthcare professionals, making it a key prerequisite for the implementation and integration of eHealth[13, 22, 30].

Our results also indicated that the majority of respondents are willing to make greater use of eHealth. However, it should be noted that acceptance of eHealth by healthcare professionals may differ in daily practice, since previous studies have found a limited acceptance of eHealth[17, 23, 39]. Acceptance is often based on prior experience, added value and social support for eHealth from colleagues[22, 40, 41]. Barriers can be overcome with continuing education for healthcare professionals, a modernized education of healthcare students that includes eHealth awareness, as well as co-creation and behavior change techniques that should be part of any implementation strategy[23, 28].

In the survey, respondents indicated a need for reliable information on types of available eHealth interventions, how they might be applied and the benefits they may have. These findings support existing literature which stresses the urgent need to provide healthcare providers with information on both effective and ineffective eHealth applications, as well as those that might suit their local context[32, 42]. Due to a rapidly changing landscape of eHealth applications, in which eHealth interventions are constantly added, updated or deleted, it is difficult for professionals to remain up to date, to determine which eHealth interventions are easy to use for older adults and to understand the assessed criteria. Our findings on benefits and usability indicate which types of eHealth interventions are easier to use or are suitable, for example, for improving the rehabilitation environment or increasing patients' self-management. Nevertheless, we do not provide a comprehensive overview. Assessment frameworks of eHealth interventions, such as the CEN-ISO/TS 82304-2 can keep pace with the development of eHealth interventions and may help healthcare professionals obtain the information necessary for informed decision making[43, 44].

Strengths and Limitations

An important strength of this study was the process of survey creation, which was comprehensive and had both valuable and executable aspects, improving the accuracy and reliability of the data analysis. Another strength of the survey was the inclusion of 513 respondents from 16 countries. This provided a good overview of the use and experiences of healthcare professionals regarding eHealth in geriatric rehabilitation. Nonetheless, some limitations of the study should be mentioned. While the study provided a broad view across a range of countries, the number of participants per country varied considerably and the majority of participants were from countries within Europe, in particular from The Netherlands and Czech Republic. This inevitably led to less reliable data for those countries with fewer respondents. Furthermore, due to the iterative development of the survey, some questions were only visible to participants outside The Netherlands, making comparisons between countries difficult. Therefore, while our paper presents the trends observed in data collected from 16 countries, our conclusions do not necessarily apply to all the countries cited in this paper. Lastly, the focus of this study was on the perspective of healthcare professionals. Future studies with a larger focus on the perspective of older adults receiving geriatric rehabilitation are needed to explore this key stakeholder's voice.

CONCLUSIONS

Our primary conclusions are (1) eHealth is not yet sufficiently integrated in geriatric rehabilitation, (2) an institution-wide strategy that addresses context-specific barriers and facilitators is critical for the successful use and implementation of eHealth, (3) eHealth interventions that are simple, tailored and preferably developed through a co-creation process are essential, especially for older adults who suffer from cognitive impairment and (4) there is an urgent need to support healthcare providers by offering training and information on how to identify, assess and use eHealth, as well as how to evaluate implementation. Future studies on this topic should focus more on greater geographic diversity, including the views and attitudes of older adults receiving geriatric rehabilitation in various contexts, as well as take account of individual characteristics such as attitudes towards eHealth, gender, ethnicity, education and social network. These studies are preferably conducted using qualitative methods, such as in-depth interviews or focus groups. Furthermore, as assessment frameworks such as the CEN-ISO/TS 82304-2 are more widely adopted, it is advisable that these frameworks are tailored to geriatric rehabilitation via a greater emphasis on usability and specific age-related limitations.

AUTHOR CONTRIBUTIONS

J.J.M.K., A.P. and E.F.v.D.v.I. conceptualized the study. J.J.M.K. prepared the original draft, conducted the analysis and the visualization of data. All authors reviewed the draft and provided feedback. All authors have read and agreed to the published version of the manuscript.

FUNDING

This research received no external funding.

Institutional Review Board Statement

This study was approved by the Medical Ethics Review Committee of Leiden–Den Haag–Delft. This study did not fall under Medical Research Involving Human Subjects legislation.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all participants included in this study.

DATA AVAILABILITY STATEMENT

The data presented in this study are available upon reasonable request from the corresponding author. Requests will be judged based on the originality of the research question and the feasibility of the analysis plan.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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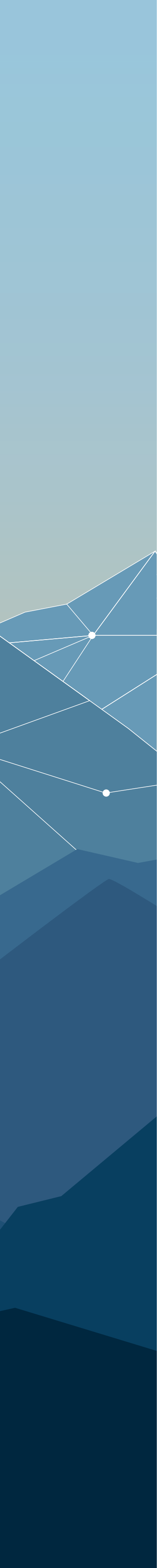

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eHealth in geriatric rehabilitation: an international consensus study.

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ABSTRACT

Purpose

Current evidence on the use of eHealth in geriatric rehabilitation is limited. This aim of this study was to achieve international consensus on three key eHealth-related topics in geriatric rehabilitation: the use, domains and scientific evaluation of eHealth. Additionally, we developed a model that provides insight into the use of eHealth in geriatric rehabilitation.

Methods

An international, two-round Delphi study was conducted. Two models served as a framework for the initial statement draft, with a total of 28 statements based on our systematic review results, an international survey and expert opinion. Eligible healthcare professionals working in geriatric rehabilitation facilities were recruited across 10 countries.

Results

Eighty healthcare professionals participated in round one and 47 in round two. In the first round, consensus was obtained for 20 of the 28 statements (71%). Prior to round two, four statements were revised, two statements were combined and one statement was removed. In round two, consensus was obtained on six statements, bringing the total to 26: three related to the use of eHealth, five to the domains of eHealth and 18 related to the scientific evaluation of eHealth.

Conclusion

International consensus has been reached on the use, domains and scientific evaluation of eHealth in geriatric rehabilitation. This first step in generating reliable knowledge and understandable information will help promote a consistent approach to the development, implementation and scientific evaluation of eHealth in geriatric rehabilitation.

Keywords: geriatric rehabilitation; eHealth; implementation; consensus; Delphi

INTRODUCTION

Against a background of an aging population, demand for geriatric rehabilitation is expected to increase substantially and will require new strategies to maintain accessible and affordable service provision. eHealth has the potential to both improve quality and preserve accessibility of geriatric rehabilitation[1-3], but the integration of eHealth in geriatric rehabilitation remains challenging[4-8].

Over the last decade, a number of definitions of eHealth have been proposed but perhaps the most commonly used and easy-to-understand states: *"The use of digital information and communication to support and/or improve health and health care"*[9]. eHealth can be applied to various domains during geriatric rehabilitation. For instance, within the monitoring domain wearable sensors can reliably and objectively assess physical activity and sedentary behaviour during rehabilitation. However, as the definition of eHealth is broad and therefore open to multiple interpretations depending on setting and context, healthcare professionals and patients in geriatric rehabilitation may have different ideas when they think or talk about use of eHealth. This may in turn negatively affect the acceptance and implementation of eHealth in geriatric rehabilitation[7, 8, 10].

In addition, the substantial increase in the variety and number of eHealth interventions has led to a rapid evolution of the eHealth landscape, resulting in scientific evidence on eHealth interventions that is diverse and often lacks usability outcomes[1, 10-12]. This lack of usability outcomes is particularly concerning given that age-related barriers may hinder the use of eHealth[13, 14]. Another concern is that patients and healthcare professionals will have difficulty identifying eHealth interventions that are effective, safe, valid and suitable to their specific needs and context[7, 15].

International consensus on the description and evaluation of eHealth will promote a more consistent approach globally to the development, implementation and scientific evaluation of eHealth in geriatric rehabilitation. In addition, a visual model that provides insight into the use and domains of health could help effectively present eHealth information and in a format, accessible for patients and healthcare professionals in geriatric rehabilitation. Therefore, the aims of this study included (1) reaching international consensus on three key topics related to eHealth in geriatric rehabilitation, namely the use of eHealth, its domains and scientific evaluation, and (2) creating a visual model that clearly explains the use and domains of eHealth in geriatric rehabilitation.

METHODS

Design

An international online Delphi study[16, 17] was conducted between October 2022 and June 2023. Two models were developed to serve as a framework for the initial draft of statements, and several statements were prepared for each of the three topics (use, domains and evaluation of eHealth). These statements were based on results from our international survey, expert opinions from researchers and findings from our systematic review on eHealth in geriatric rehabilitation. Our review concluded that eHealth has the potential to improve rehabilitation outcomes, but the lack of usability outcomes might hinder its implementation[1, 15].

Study Population and Setting

Four different groups with distinct roles participated in the study, including a research group, an expert panel, a testing group and participants: 1) The Research group initiated and coordinated the study. 2) The Expert panel, consisting of ten experts in eHealth in geriatric rehabilitation, collaborated on the conceptualization of both models, the composition and formulation of the statements, and discussed the results and the adjusted statements for subsequent rounds. Almost all initial experts were members of the European Geriatric Medical Society's 'Special Interest Group for Geriatric Rehabilitation' and were recruited through this network[18, 19]. Subsequently, expert members from outside Europe were invited to join the expert panel. Each member of the expert panel acted as a local country coordinator and was responsible for distributing the statements to participants in their country. 3) The Testing group compromised a group of five professionals who were approached by the research group to carry out technical testing of the platform and pilot the statements. 4) The Participants included healthcare professionals with experience of eHealth in geriatric rehabilitation who were (i) working in a geriatric rehabilitation setting, (ii) aged 18 years old and over, (iii) understood English, and (iv) had at least three months experience working in a geriatric rehabilitation setting. A local expert panel member approached participants with a request to rate the statements. The participating groups and their different roles are illustrated in figure 1.

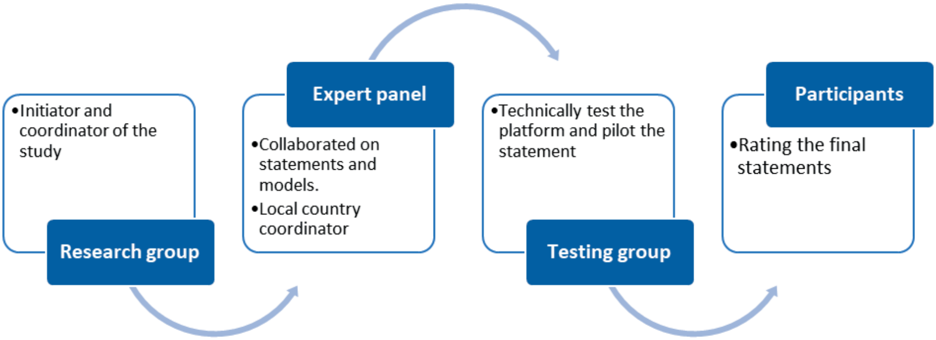

Figure 1. participating groups and their different roles

Recruitment and Consent

Eligible participants were recruited in geriatric rehabilitation services across 10 countries: Brazil, Canada, Czech Republic, Germany, Ireland, Japan, Malta, The Netherlands, South Korea and Spain. The distribution of statements varied by country depending on the personal preferences and experiences of the local expert panel member. Invitations included a link to a web-based survey that hosted the online statements, study information outlining the purpose, expected duration (15 minutes), confidentiality of responses, and contact details of the principal investigator. Participants did not receive any form of compensation. To boost response rates, a reminder was sent to participants in each country two weeks after the initial invitation. The online survey was hosted by Castor Electronic Data Capture (Castor EDC; Castor, Amsterdam, The Netherlands).

Development of models

Two models were developed based on the findings of our systematic review and international survey. The first model concerning the use of eHealth was based on the *"Healthcare value cycle"*[20], while the second model, focusing on the evaluation of eHealth, was based on the "eHealth Evaluation Cycle"[21]. Following an initial meeting, the expert panel members gave their opinions and feedback on the models. The research group then fine-tuned both models based on the feedback (see appendix, figures 1 and 2). After the last Delphi round a final visual model (based on prior models, results of the Delphi rounds and feedback from the expert panel) was created to provide insight into the use and domains of eHealth in geriatric rehabilitation.

Delphi rounds

Preparation of statements

A flowchart presenting the different Delphi rounds is illustrated in figure 2. Prior to the first round of the study, members of the expert panel took part in an online semi-structured, open-ended brainstorming session primarily focusing on reaching agreement on the content and objectives of the consensus study. The research group began by presenting two models focused on the use and evaluation of eHealth in geriatric rehabilitation. The research group used the two models as a framework to draft an initial set of statements concerning the use, domains and evaluation of eHealth in geriatric rehabilitation. The expert panel was consulted to gather feedback and the statements were adjusted based on their input. Finally, the testing group was consulted to technically assess the platform and pilot the statements.

Round 1

In the first round, participants were invited to rate each statement on a 5-point Likert scale ranging from 1 to 5, based on the level of agreement (1 = full disagreement to 5 = full agreement). Consensus on a statement was defined as 80% or more participants rating it as 4 or 5 (slight agreement, full agreement). Additionally, participants had the opportunity to clarify their answers by adding comments. The survey included 5 statements related to the use of eHealth, 5 statements about the domains of eHealth and 18 statements related to the scientific evaluation of eHealth in geriatric rehabilitation. Sociodemographic and professional characteristics of participants (sex, age, profession, working years and country of origin) were collected. The research group analysed the data from round one and when consensus was reached on a statement it was removed from consideration in the second round. Free-text comments from participants were reviewed by the research group and used to revise or remove statements that did not achieve consensus. This analysis was then presented and discussed with the expert panel.

Round 2

All members of the expert panel were requested to invite participants from the previous round. The participants' countries of origin were collected. At this stage, results from the previous round were presented to the participants. Each participant was asked to consider the mean score from the previous round and the adjustments made to the statements before re-rating them a second time. In the second and final round the survey included 2 statements related to the use of eHealth and 4 statements related to the evaluation of eHealth in geriatric rehabilitation.

Statistical Analyses

Descriptive statistics and frequency distributions were used to describe outcomes for the various statements. Surveys that were less than 90% complete were excluded from the final data analysis. Data were analysed with SPSS version 25.0.

Ethical Considerations

Approval for the study was obtained in Ireland and the Netherlands, in accordance with the regulations of the local Medical Ethics Committees. In other participating countries, ethical approval was not required. All participants signed the informed e-consent by clicking a dedicated button available in the invitation link, and by doing so they stated that they were aware that participation was voluntary.

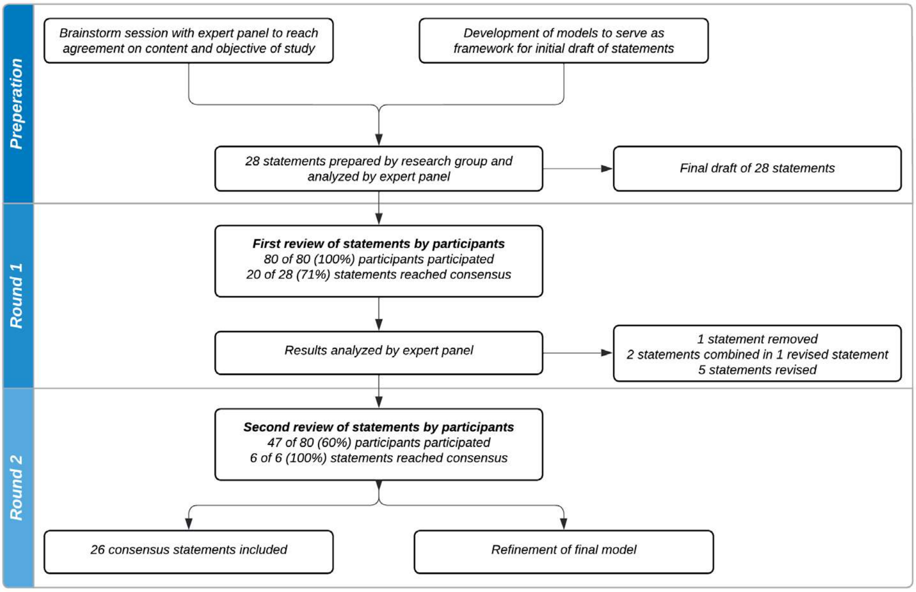

Figure 2. A flowchart illustrating the three phases of content preparation and consensus-building

RESULTS

A total of 80 participants took part in round one and 47 in round two. Participant characteristics are presented in Table 1. The median age of participants was 41 years (IQR: 29-51), the median number of years of work experience within geriatric rehabilitation was 10 (IQR 5–20), and most participants were from Europe (61%).

Table 1. Sociodemographic and professional characteristics of participants (n = 80)

	n (%)
Sex	
Female	67 (84)
Male	11 (14)
Prefer not to say	2 (2)
Age	
18–29	8 (10)
30–39	25 (31)
40–49	26 (33)
50–59	14 (17)
>60	7 (9)
Profession	
Physiotherapist	30 (38)
Medical practitioner/ geriatrician	14 (18)
Occupational therapist	17 (21)
Other*	19 (23)
Working years	
1 to 5	28 (35)
6 to 15	29 (36)
16 to 25	12 (15)
>25	11 (14)
Continent	
Europe (including the United Kingdom and Ireland)	49 (61)
North and South America	29 (36)
Asia	2 (3)

*Profession, other: researcher, dietician, manager, nurse, respiratory therapist, speech therapist

Delphi round 1

The results of all Delphi rounds are presented in Tables 2, 3 and 4. In the first round consensus was obtained on 20 of the 28 statements (71%), including consensus on 1 of 5 (20%) statements related to the use of eHealth, 5 of 5 (100%) related to the domains of eHealth and 14 of 18 (78%) statements related to the scientific evaluation of eHealth in geriatric rehabilitation.

Table 2. Statements and revised statements related to use of eHealth, results from round 1 and 2

Statements	Median (IQR)	Consensus reached* Y/N (%)
A more specific description of eHealth in GR, including the use, domains and evaluation eHealth in GR, is needed to achieve a more consistent approach of eHealth in GR.	5 (1)	Y (84)
eHealth in GR should primarily focus on:		
· (Patient-centred) rehabilitation goals	4 (1)	N (76)
· The interaction between the patient / caregiver and the healthcare professional	4 (2)	N (72)
eHealth in GR should preferably be delivered as blended care (a combination of traditional face-to-face and online care (eHealth)).	5 (1)	N (78)
Big data, artificial intelligence, and prediction models are important topics for the future use of eHealth in GR.	4 (2)	N (57)
Revised statements second round		
eHealth in geriatric rehabilitation should primarily focus on monitoring, training and self-management, and secondarily on information and counselling.	4 (1)	Y (83)
eHealth in geriatric rehabilitation should preferably be integrated into care pathways (blended care, hybrid care).	5 (1)	Y (94)

*Consensus: % of participants who rated a 4 or 5 (slightly agreement, full agreement)

Delphi round 2

Before the 2nd round, adjustments were discussed with the expert panel regarding the 8 statements on which no consensus was reached in round 1. Among the statements on eHealth use, one statement regarding the use of big data and artificial intelligence (AI) was removed because participants questioned its usefulness, ethical aspects and alignment with the topic. Two other statements were combined into one revised statement. Additionally, four statements on the topic *evaluation of eHealth* were revised based on participants' comments from the first round. Participants were invited to respond to the six revised statements and consensus was reached on all statements. The participants' countries of origin are presented in table 5.

Table 3. Statements related to the domains of eHealth, results from round 1 (n=5)

Statements	Median (IQR)	Consensus reached* Y/N (%)
For eHealth in GR it is beneficial to focus on several specific domains, such as:		
· Monitoring	4 (1)	Y (86)
· Training	4 (1)	Y (87)
· Self-management	5 (1)	Y (85)
· Information	4 (1)	Y (80)
· Consultation	4 (1)	Y (81)

*Consensus: % of participants who rated a 4 or 5 (slightly agreement, full agreement)

Table 4. Statements and revised statements related to the evaluation of eHealth, results from round 1 and 2

Statements	**Median (IQR)**	**Consensus reached* Y/N (%)**
For the development and evaluation of eHealth in GR it is useful to use the 'eHealth evaluation cycle'.	4 (1)	n (74)
Patients and professionals should be involved during each phase of the 'eHealth evaluation cycle'.	5 (1)	Y (89)
The following outcome domains should be included when evaluating eHealth in GR:		
· Usability (the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use)	5 (0)	Y (95)
· Digital health literacy	5 (1)	Y (85)
· Experiences/satisfaction	5 (1)	Y (94)
· Adverse outcomes	5 (1)	Y (87)
· (Cost)-effectiveness	4 (1)	N (79)
· Organization and local aspects (feasibility)	4 (1)	Y (90)
· Technical aspects	4.5 (1)	Y (81)
· Interoperability (a characteristic of a product or system to work with other products or systems)	4 (1)	Y (84)
· Adherence/uptake	5 (1)	Y (91)
Outcome domains related to effectiveness should be structured using the following classification systems: The International Classification of Functioning, Disability and Health classification system (ICF).	4 (2)	N (65)
Outcome measures related to usability should include clear endpoints or reliable and validated questionnaires.	5 (1)	Y (88)
Outcome measures related to usability should include one or more of the following age-related barriers:		
· Cognition	5 (0)	Y (93)
· Physical ability	5 (1)	Y (87)
· Motivation	5 (1)	Y (85)
· Perception	4 (1)	N (78)
· Guidance and support (describe usability problems that occur when the eHealth intervention does not provide sufficient support and feedback for tasks that the user must perform and (potential) errors the user makes)	5 (1)	Y (81)
Revised statements second round		
For the development and evaluation of eHealth in GR it is advised to use evidence-based evaluation frameworks such as the 'eHealth evaluation cycle'.	5 (1)	Y (92)
It is advised that outcome domains related to effectiveness should be structured using a classification system such as the Classification of Functioning, Disability and Health (ICF) or the Post-acute care rehabilitation quality model (Jesus and Hoenig, 2015).	5 (1)	Y (96)
It is advisable to include (cost) effectiveness as an outcome domain in the evaluation of eHealth in GR.	5 (1)	Y (94)
Depending on the type of eHealth intervention, outcome measures related to usability should include the following age-related barriers: perception.	5 (1)	Y (85)

Consensus: % of participants who rated a 4 or 5 (slightly agreement, full agreement)

Table 5. Country of origin from participants in round 2 (n = 46)

	n (%)
Continent	
Europe (including the United Kingdom and Ireland)	26 (55)
North and South America	8 (17)
Asia	13 (28)

Final model

The final model is shown in Figure 3. The model utilizes a patient journey to illustrate domains of eHealth that may be of added value at each phase of rehabilitation. A patient journey was incorporated into the final model in order to help patients and healthcare professionals in geriatric rehabilitation to better understand the use and timing of eHealth within the appropriate context. Since the information and consultation domains apply throughout the patient journey, both were incorporated into the other three domains (monitoring, training, and self-management).

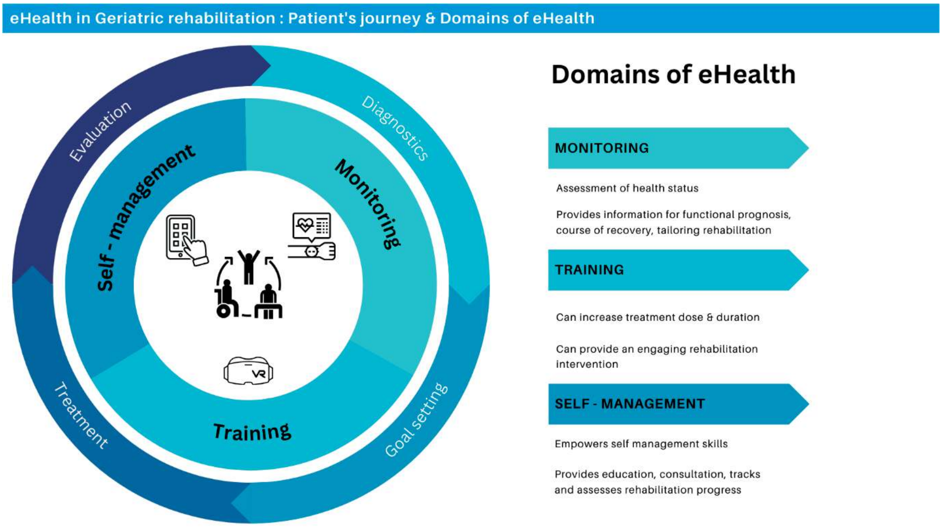

Figure 3. Final model patient's journey & domains of eHealth

Free-text comments

The free-text comments gave important insights into the participants' rationale for the various statements. These points are reported under each topic below.

Use of eHealth

Consensus was reached regarding the statement that 'a more specific description of eHealth in geriatric rehabilitation is needed'. Several participants commented that this would promote a more consistent approach to explaining the concept of eHealth to patients and professionals in geriatric rehabilitation, *"I agree, especially concerning understanding the term eHealth and explaining it to patients and other professionals in GR."* However, some participants commented that rather than a separate description specifically for geriatric rehabilitation a description for rehabilitation in general would be sufficient, *"I wonder if we need to differentiate eHealth for GR or more for rehabilitation in general."*

There was no consensus on big data, machine learning and prediction models as important topics for the future use of eHealth in geriatric rehabilitation. Multiple participants expressed concerns regarding the ethical implications and privacy considerations related to use of artificial intelligence (AI*), "..I think great caution is needed due to substantial privacy concerns around big data and lax AI regulation. AI might have a role but it will require considerable forethought and caution, as well as consideration of what fully informed consent might look like in this situation."*

Domains of eHealth

In the context of eHealth for geriatric rehabilitation, there was consensus that it would be beneficial to focus on specific domains such as monitoring. Participants noted that use of monitoring would allow eHealth to measure outcomes, in turn helping establish quantifiable goals. *"I think monitoring helps provide data that can assist in determining baseline, progress and use to measure outcomes. It is the 'measurable' part when thinking about SMART goal setting."* Similarly, there was agreement concerning a focus on training as a specific domain of eHealth. Participants commented that there is sufficient potential to justify integrating eHealth into rehabilitation treatment. *"To me, I love the idea of incorporating more of this type of technology into treatment. It keeps sessions interesting, can offer environments that are not always otherwise feasible and frees up personnel for other tasks (for example, a Rehab. Assistant or caregiver who may have to assist with the activity). Trainer and user familiarity with training devices may complicate their ability to support e-Health use."*

Evaluation of eHealth

Consensus was reached that Usability should be included as an outcome domain when evaluating eHealth in geriatric rehabilitation. Multiple respondents noted the importance of evaluating usability, especially in older adults with cognitive decline. *"Technology is not something that most of the geriatric population is familiar with; this of course will change in the future. We also need to take into consideration that people with cognitive impairment will have difficulty navigating technology."*

There was consensus on the statement that outcome domains related to effectiveness should be structured using a classification system such as the Classification of Functioning, Disability and Health (ICF). Most participants found classification systems useful for structuring outcome domains, though some suggested that alternatives might be feasible. "The ICF is likely the one classification system that is 'universally accepted' in rehabilitation, but there may be others that are a better fit for eHealth initiatives."

DISCUSSION

This study aimed to reach international consensus on three key topics related to eHealth in geriatric rehabilitation: the use of eHealth, its domains and scientific evaluation. Based on a two-round Delphi method, 80 participants from 10 countries reached consensus on 26 eHealth statements: 3 on use, 5 on the domains and 18 on the scientific evaluation of eHealth.

Our study also highlighted the need for a specific description of eHealth in geriatric rehabilitation. Over the years numerous definitions of 'eHealth' have been proposed, for example, a 2005 systematic review found 51 unique but highly heterogeneous definitions of eHealth[22]. While the appearance of so many definitions shows the widespread recognition of eHealth, this diversity may result in fragmented understanding[23]. Our final model therefore aims to provide a specific description of the use and domains of eHealth in geriatric rehabilitation, providing clear and reliable eHealth information in a format equally accessible to patients and healthcare professionals in geriatric rehabilitation.

The only excluded statement concerned big data and AI, which was removed due to the many questions raised by participants regarding use and ethics. Big data and AI are undoubtedly promising, but as a fast-emerging technology there are serious concerns regarding safety, transparency and accuracy[24-26], particularly as the complex and opaque relationships between input and output on which AI relies can yield errors that are difficult to foresee or prevent[24]. A recent systematic review identified 36 studies involving guidelines, consensus statements and standards on the application of AI in health care[27], but specific guidelines and standards on the use of AI in geriatric rehabilitation are still needed. In addition, a recently proposed quality assessment framework provides guidance on the appropriate validation steps needed to ensure safe and reliable AI-based predictive models[28]. Such frameworks and guidelines can provide a starting point for the safe and responsible implementation of AI-based prediction models in geriatric rehabilitation.

An important achievement of the study was reaching consensus on all proposed statements related to the evaluation of eHealth in geriatric rehabilitation. Almost all participants agreed that specific outcome domains such as usability should be included when evaluating eHealth in geriatric rehabilitation. Additionally, agreement was reached on the importance of incorporating age-related outcomes such as cognition, physical ability and motivation in these evaluations. The proposed age-related outcome domains were in line with the MOLD-US framework, which is an evidence-based framework of usability and age-related outcomes[13]. In current practice eHealth is often insufficiently tailored to age-related barriers, which hampers efficient use of eHealth and possibly results in non-adoption by older adults receiving geriatric rehabilitation[29]. Considering that current literature on the usability of eHealth in geriatric rehabilitation is very limited, and studies that do include usability outcomes show diverse results without clear outcome measures[1], reaching consensus on usability outcome domains is an important but challenging step towards more evidence-based practice of eHealth in geriatric rehabilitation.

Strengths and limitations

A strength of this study was the involvement of professionals from several disciplines, making the study multidisciplinary in nature. Furthermore, the majority (65%) of participants had more than 10 years working experience, enabling them to critically assess the proposed assessments. Nevertheless, several study limitations should be mentioned. While the study included 80 participants across a range of countries, the number of participants per country varied considerably and most participants were from countries within Europe. This inevitably leads to less reliable data. Due to the anonymity of participants and the fact that in the second Delphi round only the participants' countries of origin were collected, it is unknown if and to which extend participants of the second Delphi round differed from those of the first Delphi round. However, the same expert panel members were asked to disseminate the invitation to the same group of participants within their respective countries. Furthermore, to ensure participants in the second Delphi round could make informed decisions, the results from the first round were presented at the beginning of the second round. Furthermore, Boel et al[30] demonstrated that including participants who missed a previous Delphi round does not affect the final outcome. Instead, it enhances the representation of diverse opinions and even reduces the likelihood of false consensus. It is important to mention that since the survey was in English, participants in non-English-speaking countries might have been unable to participate or may have had difficulty articulating their responses clearly. This could have ultimately resulted in lower participation rates from those countries. Lastly, this study focused on the perspectives of healthcare professionals and did not consider the views of patients and caregivers. Future research on this topic is needed to incorporate their input on the current statements and gather additional feedback to refine the final model, ensuring it is both relevant and beneficial for them.

CONCLUSION

Our primary conclusion is that it is possible to achieve broad international consensus on the use and evaluation of eHealth in geriatric rehabilitation. Achieving consensus on these topics is important since it will facilitate reliable, easily understandable information on eHealth in geriatric rehabilitation for patients, healthcare professionals and researchers alike. Ultimately, this work may promote a more consistent approach to the development, implementation, scientific and safety evaluation of eHealth on a global scale in this rapidly growing area of healthcare.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY STATEMENT

The data presented in this study are available upon reasonable request from the corresponding author. Requests will be judged based on the originality of the research question and the feasibility of the analysis plan.

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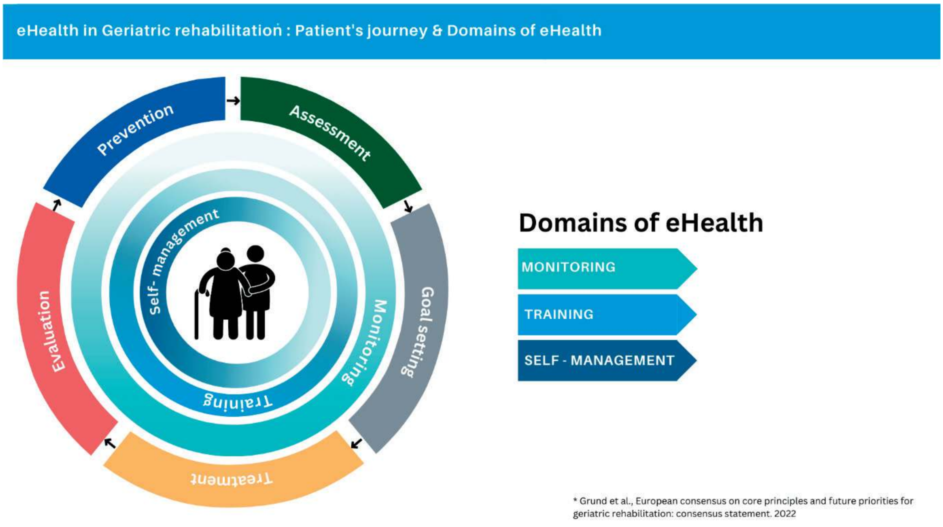
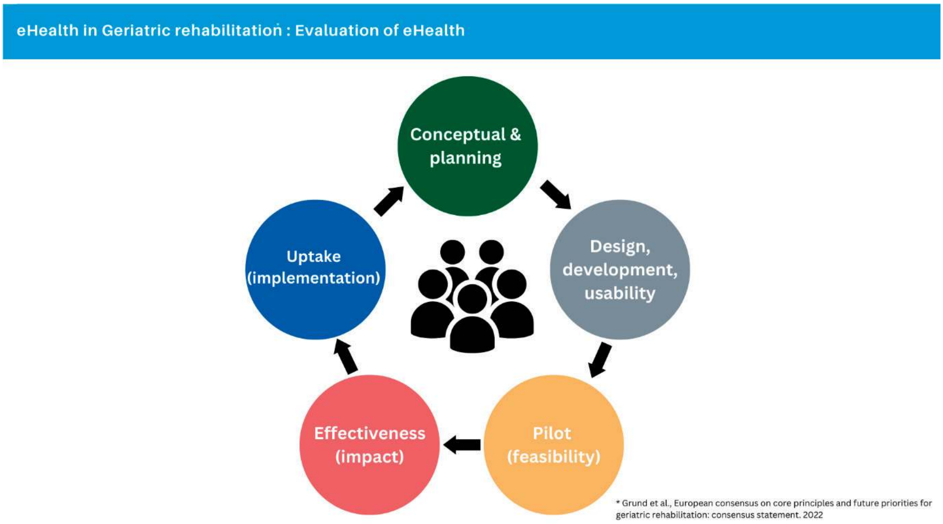
APPENDIX : ORIGINAL MODELS


eHealth in Geriatric rehabilitation : Patient's journey & Domains of eHealth

* Grund et al., European consensus on core principles and future priorities for geriatric rehabilitation: consensus statement. 2022

Figure 1. original model: use of eHealth


eHealth in Geriatric rehabilitation : Evaluation of eHealth

* Grund et al., European consensus on core principles and future priorities for geriatric rehabilitation: consensus statement. 2022

Figure 2. eHealth evaluation cycle

Original online statements

Introduction

eHealth geriatric rehabilitation (GR) has the potential to improve outcomes that matter to patients, their caregivers, healthcare professionals and society. However, eHealth is not yet sufficiently integrated in geriatric rehabilitation, mainly due to the implementation of eHealth being complex, time-consuming, and it often requires a change in workflow to successfully integrate eHealth in daily practice(1-5). Furthermore, the landscape of eHealth applications is changing rapidly, with a wide variety of eHealth interventions constantly being added, updated or deleted. As a result, the scientific evidence on effectiveness, feasibility and usability of these eHealth interventions often lags behind (6-8). In addition, eHealth interventions, especially mobile apps, have a broad quality range, are rarely subjected to rigorous scientific evaluation and often lack in privacy and security features(9). This makes it difficult for patients and healthcare professionals to comprehend which eHealth interventions are safe and suitable to fit their specific needs and contexts. Lastly, the current scientific evidence on eHealth in GR is diverse and often lacks specific age-related outcome domains such as usability, making it hard to compare outcomes and difficult to assess whether the examined eHealth intervention is usable for older adults (10).

The aim of this study is to develop a consensus on the use, domains and evaluation of eHealth in GR with the potential to enable informed decision making, facilitate uniformity in research through the use of evaluation frameworks and the standardization of outcome domains to ultimately promote the implementation and integration of eHealth in GR.

Several statements were prepared for each of the three topics. Each topic is accompanied by a brief introduction explaining the rationale for choosing this topic and what each topic covers. We would like to ask you to go through each statement carefully and rate the level of agreement (1 = full disagreement 5 = full agreement). After each statement it is possible to comment on the content or formulation of the statement in the free text boxes.

Topic 1: eHealth in GR

In the last decade several definitions of eHealth have been proposed of which the most frequently used and easy to understand definition is: "The use of digital information and communication to support and/or improve health and health care."(11). However, this definition is very broad and therefore open to multiple interpretations depending on setting and context such as GR. In the absence of a more specific definition or description, patients and healthcare professionals in the GR may have a different understanding of what they mean when they think or talk about the use of eHealth and its goals, which in turn may negatively affect the acceptance of eHealth in the GR (4-6). Therefore, consensus on a more specific description and the main goals of eHealth in GR could help to achieve a more consistent approach in the development, implementation and scientific evaluation of eHealth in GR. Furthermore, it could facilitate the provision of reliable and easily understood information on eHealth to patients and healthcare professionals in GR.

1.1A more specific description of eHealth in GR, including the use, domains and evaluation eHealth in GR, is needed to achieve a more consistent approach of eHealth in GR

1.2 eHealth in GR should primarily focus on:

- (Patient-centered) Rehabilitation goals
- The interaction between the patient / caregiver and the healthcare professional

1.3 eHealth in GR should preferably be delivered as blended care (a combination of traditional face-to-face and online care (eHealth))

1.4 Big data (a combination of structured, semi-structured and unstructured data that can be used for information in machine learning) and prediction models are important topics for the future use of eHealth in GR

Topic 2: Domains of eHealth

A next step for a more specific description of eHealth is to specify the domains in which eHealth can be beneficial. For inspiration, we have developed a model that represents the patient's journey and covers different domains where eHealth can be beneficial. For each domain, we have added examples of different forms of eHealth that can be used. We developed this model based on findings from the literature, an international survey, and opinions of expert group involving healthcare professionals and researchers in the field of eHealth and GR. The model can be found here Defining domains can help patients and healthcare professionals to better understand what eHealth in GR is truly about. Furthermore, defining domains also helps patients and healthcare professionals better understand which forms of eHealth are more suitable / appropriate in certain domains of GR.

2.1 For eHealth in GR, it is beneficial to focus on several specific domains, such as (choose 1 or more):

- Monitoring (see link to model for further explanation and examples)
- Training (see link to model for further explanation and examples)
- Self-management (see link to model for further explanation and examples)
- Information
- Consultation
- Other, namely:
- Other, namely:
- Other, namely:

Topic 3: Evaluation of eHealth

eHealth solutions are considered complex interventions. Studying such interventions requires multiple evaluation approaches that can capture the complexity of successive phases of intervention, development and implementation. Evaluating eHealth is critical before starting implementation and adoption of usable and effective eHealth programs. Additionally, for the evaluation of eHealth in GR, it may be useful to include specific outcome domains such as usability and digital health literacy, since these variables have a significant impact on successful implementation. Consensus on eHealth evaluation is needed to provide a clear overview of evaluation approaches that are suitable in GR, thereby facilitating the development and implementation of eHealth in GR.

3.1 For the development and evaluation of eHealth in GR it is useful to use the 'eHealth evaluation cycle'

3.2 Patients and professionals should be involved during each phase of the 'eHealth evaluation cycle'

3.3 The following outcome domains should be included when evaluating eHealth in GR (choose 1 or more):

- Usability (The extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use)
- Digital health literacy
- Experiences/satisfaction
- Adverse outcomes
- (Cost)-effectiveness
- Organization and local aspects (feasibility)
- Technical aspects

- Interoperability (a characteristic of a product or system to work with other products or systems)
- Adherence/uptake
- Other, namely:
- Other, namely:
- Other, namely:

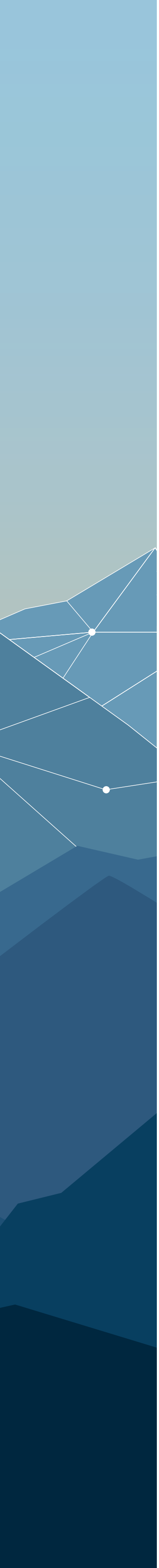
3.4 Outcome domains related to **effectiveness** should be structured using the following classification systems:

- The International Classification of Functioning, Disability and Health classification system (ICF), a classification of health and health-related domains, link)
- Other, namely:
- Other, namely:
- Other, namely:

3.5 Outcome measures related to **usability** should include clear endpoints or reliable and validated questionnaires

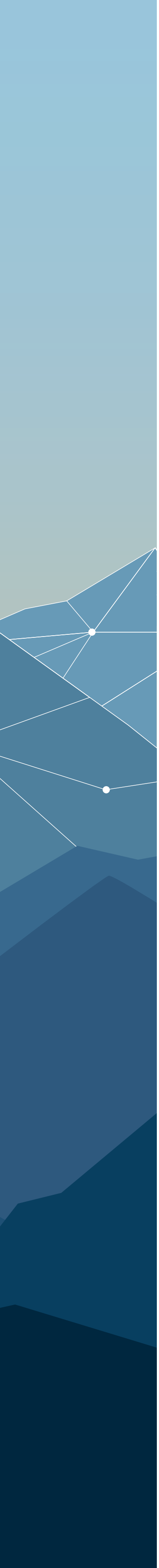
3.6 Outcome measures related to **usability** should include one or more of the following age-related barriers:

- Cognition
- Physical ability
- Motivation
- Perception
- Guidance and support (describe usability problems that occur when the eHealth intervention does not provide sufficient support and feedback for tasks that the user must perform and (potential) errors the user makes)
- Other, namely:
- Other, namely:
- Other, namely:



Part 2

Wearable sensors to enhance geriatric rehabilitation



5

Improving the prediction of functional recovery in older adults with stroke in geriatric rehabilitation using an inertial measurement unit combined with the Utrecht Scale for Evaluation of Rehabilitation (USER)

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Submitted

ABSTRACT

Background

Prediction of functional recovery in older adults recovering from stroke is typically based on observational scales, such as The Utrecht Scale for Evaluation of Rehabilitation (USER). Objectively measuring postural sway using inertial measurement devices (IMU) may complement or improve conventional approaches. The aim of this study was to evaluate whether integrating an IMU with USER data enhances the accuracy of predicting functional recovery at discharge.

Methods

This prospective cohort study included older adults (≥ 65 years) recovering from stroke. Postural sway was assessed using an IMU. Using three different regression models, percentage explained variance was compared to assess predictive performance on functional recovery of USER versus an IMU.

Results

The 71 patients included had a mean age of 78 (SD 7.6) and a median time since stroke of 16 days (IRQ 19-60). Incorporation of both balance conditions in the final model increased the explained variance compared to a model in which only USER-mobility at admission was used to predict delta-USER at discharge (R2 = 0.61 vs. 0.30).

Conclusions

Sitting and standing balance as measured by an IMU improves the prediction of functional recovery at discharge compared to USER alone.

INTRODUCTION

With an aging global population, the number of older adults experiencing stroke is increasing rapidly[1]. Older adults who experience stroke often show residual functional or emotional problems, cognitive impairment and fatigue[2]. Geriatric Rehabilitation (GR) is a multidimensional collection of diagnostic and therapeutic interventions that play an important role in aiding older adults recover and regain their independence after stroke. The goal of GR is to optimize functional capacity, promote activity and maintain functional reserve and social participation in older people with disabling impairments[3].

Predicting functional recovery at the start of geriatric rehabilitation is important for the organization and content of a rehabilitation program, informing and setting patient expectations, and as preparation for the discharge procedure. Studies have determined that age, stroke severity, balance, visual-spatial perception and independence of functioning on Activities of Daily Living (ADL) on admission are important determinants of functional recovery during geriatric rehabilitation[4-6]. These determinants are conventionally assessed using clinical scales such as the National Institutes of Health Stroke Scale (NIHSS[7] for stroke severity, Barthel index (BI)[8] for ADL independence and Berg Balance Scale (BBS)[9] for assessing balance.

A promising multidimensional observational instrument for use during geriatric rehabilitation is the Utrecht Scale for Evaluation of Rehabilitation (USER). USER was specifically developed to assess progress during rehabilitation and includes items for mobility, selfcare and cognitive function[10], combining sufficient clinometric properties of geriatric rehabilitation[11, 12]. A previous study that assessed the predictive value of USER in geriatric rehabilitation found that it accurately predicted length of stay and discharge location after geriatric rehabilitation[14]. However, validated clinical observational scales have limitations, mainly due to a dependence on the skill and experience of the assessor for scoring and interpretation[15]. Therefore, an objective assessment tool would represent an interesting alternative.

In recent years novel eHealth solutions, such as Inertial Measurement Units (IMU), have proven their worth in objectively measuring and recording human movement (e.g., body posture and upper and lower extremity movements)[16]. Compared with clinical scales, data derived from an IMU generally assess different domains of the International Classification of Function, Disability and Health[17]. For example, an IMU can assess postural sway (ICF domain: body functions & structures), whereas a clinical scale can assess mobility (ICF domain: activities). A potential added value of an IMU is the ability to complement data obtained with clinical scales, thus integrating data from different

ICF domains. This type of data integration not only improves clinical observations and data quality[18, 19], but also generates a unique patient digital phenotype[20], insights from which in turn contribute to improved accuracy of functional recovery prediction. Recent studies have indeed shown that, by measuring postural sway, an IMU can reliably assess sitting and standing balance after stroke[21, 22]. While an IMU could potentially improve accuracy, to date IMUs have not been used to complement or improve data obtained with clinical scales.

Using an IMU, in this study we added sitting and standing balance to conventional USER outcomes in order to predict functional recovery. Our aim was to determine whether these IMU measurements, when combined with USER data, improve the prediction of functional recovery at discharge in older adults recovering from stroke during geriatric rehabilitation.

METHODS

Design & population

In this prospective cohort study, participants were recruited from four geriatric rehabilitation centres in the Netherlands between January 2020 and December 2022. All participants were older adults (≥ 65 years) and had been diagnosed with stroke. Eligible participants were in the sub-acute phase after stroke, were able to comprehend and sign the informed consent and were capable of understanding and performing simple tasks. Participants were excluded if they were medically unstable or were unable to sit for at least one minute without support. All participants gave written informed consent. The study protocol received a waiver of consent from the Utrecht medical ethical review committee (METC number: 20–462/C). Data were collected by a physiotherapist and transferred to the researchers as anonymized data untraceable to any individual person.

Assessments

Baseline characteristics were assessed during admission and comprised age, sex, body mass index (BMI), time since stroke, type of stroke and hemiparetic side. The following assessments were registered at admission and discharge: Activities of Daily Living functioning (ADL) was measured using the Barthel index (range 0-20, higher scores indicate a better ADL performance)[8]. Balance was assessed using the Berg Balance scale (range,0-56, higher scores indicate a better balance)[9] and the Trunk Control Test (range 0-100, higher scores indicate a better trunk balance)[23]. Mobility was evaluated using the Functional Ambulation Classification (FAC) (ranges from 0: non-functional walking to

5: independent walking outside)[24] and USER -mobility scale (range 0-35, higher scores indicate a better mobility)[10]. All assessments were standard components of routine care.

The USER is an observational instrument that measures physical (independence in ADL activities, mobility and selfcare) and cognitive function. For the purposes of this study we used only the 'mobility' subscale, which consists of seven items (sitting, standing, transfers, indoor walking, outdoor walking, climbing stairs, wheelchair use). Each item is scored on a 6-point scale (0-5), reflecting different grades of independence, use of aids and difficulty. The clinometric properties of USER were assessed in a previous study, which showed sufficient content validity, internal consistency, interrater reliability and responsiveness in geriatric rehabilitation[11, 12].

In addition to the clinical instruments, two different balance conditions were measured during the first week of admission, one sitting and one standing. A balance condition was excluded if a participant was unable to perform the condition. The conditions were arranged based on difficulty and executed in the following order: i) sitting unsupported on a wobble cushion with feet touching the ground and knees at a 90° angle for 60 seconds, and ii) standing unsupported with feet in self-selected position for 60 seconds.

Balance conditions were measured using an inertial measurement unit (manufactured by Aemics B.V. Oldenzaal, The Netherlands), which includes a triaxial accelerometer and gyroscope with a 104x per second sampling rate. The IMU was placed at the estimated height of the participant's center of mass; for the seated balance condition the IMU was placed on the upper back at the T7 level, while for the standing balance condition the IMU was placed on the lower back at the L5/S1 level. The reliability of these balance conditions has been assessed in a previous study and shown to be good to excellent (intraclass correlation coefficient > 0.75)[21]. In total, 35 sway features were calculated for every condition, consisting of 21 spatial- temporal features, 8 frequency features and 6 complexity features, which together describe the quantity, variability and consistency of movements during the assessment[22]. Postural sway is the movement of the centre of mass while in a standing position[25], with increased postural sway generally indicating poor balance[26]. A visualization of postural sway during balance condition 2 is shown in Figure 1.

Figure 1: Visualization of postural sway during balance condition 2
This visualization represents the trajectory of the sensor during measurement in two directions. On the horizontal axis: medio-lateral direction; vertical axis: anterior-posterior direction. A larger surface area presents as greater degree of postural sway, which indicates poorer balance

Statistical analysis

Normality of data was tested using the Shapiro-Wilk test. Pearson's R was used for normally distributed data, which are presented as means with standard deviations (±). Spearman's rho was used for non-normally distributed data, which are presented as medians with interquartile range (IQR). Outliers for both balance conditions were identified by standardizing with Z-scores, with Z-scores +/-3 greater than zero removed. Data were analysed using SPSS version 25.0.

Selection of sway features by principal component analysis

Since all 35 features from the IMU quantify postural sway, they may contain redundant information[21]. To address this issue, a principal component analysis (PCA) was performed to reduce the number of dimensions for the two included balance conditions while retaining maximum information[27]. Prior to the PCA, the sampling adequacy of all balance conditions was estimated using the Kaiser-Meyer-Olkin measure (KMO). An overall KMO and a per-feature KMO exceeding 0.7 and 0.5 were considered acceptable for analysis[28]. To evaluate the robustness and reliability of the principal components, we used test and retest data from a study conducted by Felius et al.[21].

Predictive modelling

The first principal components of both balance conditions were included as predictors in the regression analysis. Independence of observations was assessed using Durbin-Watson and variables were assessed for multicollinearity with the variance inflation factor (VIF). Three different regression models were created, with the USER-DELTA (USER-mobility score at discharge minus USER-mobility score at admission) as dependent variable. As independent variables, the first model included the USER-mobility score at admission, the second model included principal components of the balance conditions, and the third model included both the USER-mobility score at admission and the principal components of the balance conditions B1 and B2. The R-squared value and percentage of variance explained (PVE) were compared between the models. Patients with a maximum (optimal) score for USER-mobility at admission were excluded as this precludes evaluation of the functional recovery level (DELTA-USER). Patients who were unable to perform balance condition 2 were also excluded.

To fully understand our main results, we included additional (post-hoc) analyses investigating whether any subgroups would benefit from the addition of IMU sitting and standing balance assessments to the conventional USER assessment. In older adults recovering from stroke, the degree of sitting and standing balance, and therefore mobility, may vary greatly between patients on admission, making some balance assessments very difficult or impossible for some patients while they are too easy for others. We hypothesized that for certain subgroups, based on their level of mobility on admission, sitting and standing balance as measured by an IMU would likely be more accurate in predicting functional recovery after stroke. We therefore defined three groups based on their level of mobility independence on admission as measured by the FAC. Group FAC 0 consisted of non-ambulatory participants (FAC score: 0); group FAC 1-3 consisted of participants who needed support during mobilization (FAC score: 1-3); while group FAC 4-5 included participants who could mobilize independently (FAC score: 4-5). All models were analysed for the entire population, as well as for subgroups defined by the FAC score. Patients who were unable to perform balance condition 2 were excluded.

RESULTS

A total of 71 patients were included in the study. Three patients were excluded from analyses due to insufficient data. Patient's characteristics are described in detail in Table 1. The mean age of patients was 78 (SD 7.6), and 38 patients (51%) were male. Regarding type of stroke, 58 (82%) had an ischemic stroke, 11 (15%) a haemorrhagic stroke and 2 (3%) a subarachnoid stroke.

Table 1. Patient characteristics at baseline (Mean ±, Median (IQR))

Characteristics	n= 71
Age (years)	78 ± 7.6
Sex, male (%)	38 (51%)
BMI (kg/m2)	25.5 (23 – 28)
Type of stroke	
Ischemic	58 (82%)
Haemorrhagic	11 (15%)
Subarachnoid	2 (3%)
Hemiparetic side	
Left	33 (46%)
Right	22 (31%)
Both sides	2 (3%)
Other	14 (20%)
Time since stroke (days)	16 (12 –25)
Length of stay (days)	35 (19 – 60)
Barthel Index	12 ± 4.6
Berg Balance scale	31 (12 – 46)
Trunk Control Test	100 (75 – 100)
Functional Ambulation Classification	
Non-ambulatory (FAC 0)	25 (35%)
Dependent (FAC 1-3)	27 (38%)
Independent (FAC 4-5)	19 (27%)
USER-mobility baseline	17 ± 9.4
USER-mobility discharge	29 (24 – 33)
USER Delta mobility	11 ± 7.2

BMI: body mass index, USER: Utrecht Scale for Evaluation of Rehabilitation, IQR: interquartile range, FAC: Functional Ambulation Classification

Selection of sway features by principal component analysis

For the PCA, 12 out of 35 postural sway features were selected based on demonstrated reliability across all IMU balance tasks. The overall KMO of each condition exceeded 0.5, indicating the suitability of conducting the PCA. PCA including all conditions resulted in two principal components with eigenvalues greater than 1. For each task, more than 80% of the variance was captured in the two principal components. All principal components were measured with good-excellent reliability (ICC > 0.7).

Predictive performance

For the predictive modelling, patients with a maximum (optimal) score for USER-mobility at admission (n= 3) or who were unable to perform balance condition 2 (n= 12) were excluded. The results of the three regression models are presented in Table 2. In the linear regression analyses, the components of the balance conditions alone did not demonstrate significant contributions in Model 2 ($p > 0.05$). In the final model, which also included the USER-mobility score at admission as an independent variable, both balance conditions showed a significant contribution. The incorporation of the principal components of the balance condition in the final model led to an increased explained variance compared to Model 1, where only the USER-mobility at admission was included as an independent variable (R2 = 0.61 vs. 0.30).

Table 2. Predictive performance of USER-M and balance conditions on functional recovery at discharge

Model	Dependent variable	R^{2*}	*d*	Independent variable	*B*	β	T	*p*	VIF
USER-M	USER-DELTA	0.30	1.77	(Constant)	18.54				
				USER-M	-0.45	-0.59	-5.27	0.00	1.00
Balance conditions	USER-DELTA	-0.04	0.96	(Constant)	11.08				
				B1 - PC 1	-0.16	-0.05	-0.30	0.77	1.33
				B2 - PC 1	0.01	0.00	-0.03	0.99	1.33
USER-M + Balance conditions	USER-DELTA	0.61	2.17	(Constant)	25.04				
				USER-M	-0.80	-0.87	-8.93	0.00	1.21
				B1 - PC 1	0.87	0.26	2.43	0.02	1.45
				B2 - PC 1	-1.81	-0.43	-3.81	0.00	1.59

*: adjusted, d: Durbin-Watson, B: unstandardized beta, β: standardized beta, T: the t test statistic), B1- B2: Balance condition 1 and 2, PC: Principal component, USER-M: Utrecht Scale for Evaluation of Rehabilitation – mobility, USER-DELTA: USER-mobility score at discharge minus USER-mobility score at admission

Comparison between subgroups

Characteristics of the additional post-hoc subgroup analyses are described in Table 3. The results of the three regression models, per subgroup, are presented in Table 4. For the regression analyses only 13 patients could be included in subgroup 1, as only 13 out of 25 were able to complete balance condition 2. In the first model, the USER-mobility score at admission alone did not demonstrate significant contributions in the FAC: 0 subgroup (p > 0.05). Similarly, for all subgroups the components of the balance conditions alone did not demonstrate significant contributions in Model 2 (p > 0.05). In the final model, the combination of principal components with USER-mobility at admission led to an increased explained variance compared to the first model for subgroups FAC: 1-3 (R2 = 0.63 vs. 0.58) and FAC: 4-5 (R2 = 0.47 vs. 0.34).

Table 3. Characteristics of subgroups based on level of mobility on admission (Mean ±, Median (IQR))

	Not ambulatory (n = 25)	Require assistance (n =27)	Mobilize independently (n = 19)
Age (years)	77.3 ± 9.1	76.3 ± 11.3	79.1 ± 8.1
Sex, male (%)	12 (48%)	16 (59%)	9 (47%)
Barthel Index	7.71 ± 4.1	13.76 ± 3.4	14.1 ± 3.4
Berg Balance scale	8.0 (3.5 – 29.0)	44.0 (31.0 – 48.0)	45.0 (38.0 – 81.0)
Trunk Control Test	75 (55- 100)	100 (87 – 100)	100 (100 – 100)
USER-mobility baseline	7.80 ± 5.5	18.21 ± 7.1	24.31 ± 5.3
USER-mobility discharge	23 (15.8 – 30.5)	30 (27.0 – 33.8)	33.5 (30.3 – 35.0)
USER Delta mobility	14.25 ± 7.2	11.48 ± 6.9	7.31 ± 5.2
Length of stay (days)	53.0 (35.0 – 92.0)	33.5 (17.5 – 50.0)	20.0 (9.3 – 27.8)
Completed balance assessment			
Balance condition 1 (N(%))	20 (80%)	26 (96%)	19 (100%)
Balance condition 2	13 (52%)	26 (96%)	19 (100%)
B1 - PC 1	1.34	0.35	0.14
B2 - PC 1	0.6	-0.16	-0.93

Groups: not ambulatory (FAC 0), require assistance (FAC 1-3), mobilize independently (FAC 4-5), USER-M: Utrecht Scale for Evaluation of Rehabilitation – mobility, USER-DELTA: USER-mobility score at discharge minus USER-mobility score at admission. B1- B2: Balance condition 1 and 2, PC: Principal component B1 – PC 1, B2 – PC 1: lower scores indicate less sway and better balance

Table 4. Predictive performance per subgroup of USER-M and balance conditions

Model	Dependent variable	Group	R^{2*}	*d*	Independent variable	*B*	β	T	*p*	VIF
USER-M	USER-DELTA				(Constant)	15.23				
		Not ambulatory	-0.35	1.77	USER-M	-0.13	0.27	0.46	0.65	1.0
					(Constant)	26.46				
		Require assistance	0.58	2.47	USER-M	-0.84	-0.77	-5.64	0.00	1.0
					(Constant)	25.13				
		Mobilize independently	0.34	2.76	USER-M	-0.73	-0.62	-2.97	0.01	1.0

Balance conditions	USER-DELTA	Not ambulatory	0.09	1.16	(Constant)	15.32				
					B1 - PC 1	1.32	0.32	1.03	0.32	1.07
					B2 - PC 1	-1.38	-0.39	-1.25	0.24	1.07
		Requires assistance	-0.29	1.81	(Constant)	11.80				
					B1 - PC 1	-0.08	-0.03	-0.10	0.92	1.71
					B2 - PC 1	-1.05	-0.24	-0.24	0.41	1.71
		Mobilize independently	-0.50	1.37	(Constant)	6.01				
					B1 - PC 1	1.11	0.39	1.13	0.28	1.67
					B2 - PC 1	-0.97	-0.23	-0.66	0.52	1.67
USER-M + Balance conditions	USER-DELTA	Not ambulatory	0.07	1.71	(Constant)	21.95				
					USER-M	-0.57	-0.39	-1.25	0.25	1.31
					B1 - PC 1	1.16	-0.28	0.93	0.38	1.09
					B2 - PC 1	-1.79	-0.51	-1.61	0.15	1.18
		Require assistance	0.63	2.93	(Constant)	26.14				
					USER-M	-0.83	-0.80	-5.84	0.00	1.04
					B1 - PC 1	0.47	0.17	.93	0.37	1.77
					B2 - PC 1	-1.40	-0.32	-1.85	0.08	1.72
		Mobilize independently	0.47	2.45	(Constant)	25.87				
					USER-M	-0.87	-0.74	-3.71	0.00	1.1
					B1 - PC 1	1.50	0.52	2.13	0.06	1.71
					B2 - PC 1	-2.26	-0.53	-2.07	0.06	1.86

*: adjusted, *d*: Durbin-Watson, *B:* unstandardized beta, *β:* standardized beta, T: the t test statistic), B1- B2: Balance condition 1 and 2, PC: Principal component, USER-M: Utrecht Scale for Evaluation of Rehabilitation – mobility, USER-DELTA: USER-mobility score at discharge minus USER-mobility score at admission, Groups: not ambulatory (FAC 0), require assistance (FAC 1-3), mobilize independently (FAC 4-5)

DISCUSSION

Principal findings

In this study we investigated whether an IMU, when combined with USER, can improve the prediction of functional recovery in older adults with stroke in geriatric rehabilitation. Our two main findings were: 1) combining sitting and standing balance as measured by an IMU with USER data improves the prediction of functional recovery at discharge compared to USER alone; 2) use of IMU data was not possible for non- ambulatory patients (FAC=0).

Comparison with previous studies

A distinctive feature of this study was the integration of assessments made across different ICF domains. Our results demonstrate that combining sitting and standing balance as measured by an IMU (ICF domain: body functions & structures) with USER data (ICF domain: activities) improves the prediction of functional recovery. These results are in line with previous studies that examined prediction of rehabilitation outcomes using technology-derived data[29-31]. For instance, O'Brien et al. utilized data from an IMU obtained during a brief bout of walking at admission and found that it improved the prediction of discharge walking ability in post-stroke rehabilitation[29]. Similarly, Sprint et al. investigated the use of IMU data during ambulatory tasks to predict clinical outcomes of functional independence at discharge as measured by the FIM[31]. The performance of predictive models improved when incorporating data from multiple measurements[31], and when clinical scale data were combined with data derived from an IMU[29]. However, as these studies used different clinical scales, different algorithm models, different motor functions and different prediction models, comparison of results is difficult.

In our study a prediction model that only included balance conditions as assessed by the IMU did not yield a statistically significant prediction of the delta USER at discharge. This lack of significance may be due to the distinct constructs assessed by the IMU and the USER; specifically, the IMU assesses body structures and functions, whereas the USER focuses on activities. Zarrifa et al. reported comparable findings, where certain measured constructs acquired through upper limb robotics were deemed less critical for predicting functional abilities as evaluated by clinical scales. The measured construct likely had minimal impact on functionality as defined by the clinical scale assessing functional recovery[32].

In our post-hoc subgroup analysis, our findings specifically indicate a higher accuracy in predicting functional recovery after stroke for one subgroup: patients requiring assistance with mobilization (FAC: 1-3). Conversely, none of the models applied to the non-ambulatory subgroup of participants (FAC score: 0) produced a statistically significant prediction of the delta USER at discharge. This difference in results is presumably a result of the low number patients in the non-ambulatory subgroup who were capable of completing balance condition 2 (52%). Moreover, the balance scores for the non-ambulatory group (FAC score: 0) are likely very homogeneous compared to the other two groups (FAC 1-3 and FAC 4-5), with the insufficient variation in the dependent variable explaining why it did not significantly predict the USER delta.

Strengths and Limitations

To the best of our knowledge, this study is the first attempt to generate insights into the usefulness of IMU-dependent balance condition assessment for improving the prediction of functional recovery after stroke in geriatric rehabilitation within specific subgroups. This study contributes not only to understanding issues related to the accuracy of predicting functional recovery but also provides valuable information regarding the feasibility of conducting balance condition assessments using an IMU. This study had several strengths. Regarding the IMU, we used a rigorous data collection method to obtain objective, accurate and reliable assessments of sitting and standing balance, providing comprehensive insights into balance conditions. Additionally, the inclusion of post-hoc subgroup analyses contributed to a nuanced understanding of the main findings and offered valuable insights into feasibility. Our findings suggest that the challenge level of balance measurements should align with the individual patient's capabilities. It is crucial to ensure that the balance assessment is not excessively difficult, preventing patients from successfully completing the measurement.

However, we also acknowledge certain limitations of the study. The relatively small sample size may limit generalizability of the results to a broader population of older individuals recovering from stroke in geriatric rehabilitation. This limitation is particularly relevant for a subset of non-ambulatory patients (FAC = 0), who were unable to complete balance condition 2 and were therefore excluded from the predictive modelling analysis. Consequently, our findings from the predictive modelling analysis do not apply to this subgroup. Since the use of an IMU requires a minimum level of physical performance from the participant, utilizing IMU data to predict functional recovery appears less feasible for non-ambulatory patients. Furthermore, while the results from the post hoc subgroup analyses were promising, the number of patients per subgroup was small. Lastly, while the incorporation of IMU data in the final model led to an increased the explained variance compared to a model that included only the USER-mobility score at admission, it is crucial for future studies to assess its clinical relevance, preferably by validating of these prediction models with a larger sample size.

By integrating technology-derived data with clinical scales, providing insights across multiple ICF domains, thereby offering a comprehensive understanding of a patient's unique digital phenotype[20] and motor phenotype[34]. This integration opens avenues for "precision rehabilitation"[35] facilitating the design of tailored rehabilitation interventions aligned with the patient's capacity, potentially increasing the likelihood of an individual or subgroup responding more effectively to specific treatments[35].

CONCLUSION

In conclusion, complementing clinical scales with technology-derived data improves the prediction of functional recovery in older adults recovering from stroke during geriatric rehabilitation. This approach can also improve the accuracy of functional recovery prediction in patients requiring mobilization assistance compared to non-ambulatory patients. Future research should prioritize the validation of these prediction models, preferably using a larger sample size, which will enable more precise assessment of IMU-determined balance conditions, particularly within specific subgroups.

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Declaration of conflicting interests

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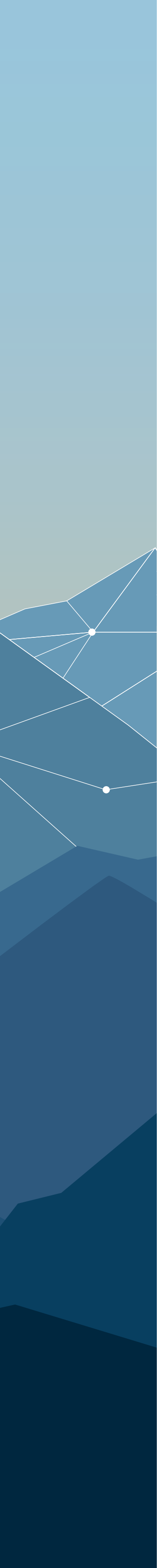

6

Changes in physical activity and sedentary behaviour following geriatric rehabilitation in older adults with stroke

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Submitted

ABSTRACT

Background

Older adults recovering from stroke engage in low levels of physical activity and spend long periods in sedentary behaviour. Sedentary behaviour and patterns of sedentary behaviour during geriatric rehabilitation are still poorly understood. The aims of this study were to quantify physical activity, sedentary behaviour and accompanying patterns of change during geriatric rehabilitation, and to potentially identify subgroups exhibiting specific patterns of change in physical activity and sedentary behaviour.

Methods

Older adults (≥70 years) recovering from stroke were included in this prospective cohort study. Patients wore an inertial measurement unit (IMU) on the ankle for 48 hours, with data collected between 7am and 11pm. Variables related to physical activity, sedentary behaviour and patterns of sedentary behaviour were calculated and analysed. Extracted principal components on admission and discharge were plotted in order to define possible subgroups based on degree of change.

Results

In total, 53 patients with sufficient accelerometer wear time were included. The degree of change in physical activity and sedentary behaviour components was extremely diverse. Except for step count (P = 0.01), no significant changes were observed in any variable related to physical activity, sedentary behaviour or patterns of sedentary behaviour between admission and discharge.

Conclusions

Older adults recovering from stroke during geriatric rehabilitation improve their functional performance, but show little change in physical activity, sedentary behaviour or patterns of sedentary behaviour. The degree of change in physical activity and sedentary behaviour was highly diverse and no subgroups could be defined.

Keywords: Geriatric rehabilitation, physical activity, sedentary behaviour, accelerometer, stroke

INTRODUCTION

The incidence of stroke among older adults is rising swiftly as the world's population ages Following stroke, older adults often face ongoing challenges such as functional or emotional issues, cognitive decline and fatigue. Geriatric rehabilitation plays a vital role in the recovery of independence of older adults following stroke. Geriatric rehabilitation is a multidimensional approach comprising diagnostic and therapeutic interventions that focus on optimizing functional capacity, promoting activity and preserving functional reserves and social participation in older people with disabling impairments[1].

While promoting physical activity is a key concept during geriatric rehabilitation, several studies have reported that, post-stroke, many older adults engage in very low levels of physical activity and spend prolonged periods in sedentary behaviour[2, 3]. Physical activity, often categorized by intensity, refers to any body movement that raises energy expenditure above resting levels[4]. Sedentary behaviour is defined as behaviour resulting in energy expenditure ≤1.5 metabolic equivalents (METs) while in a sitting, reclining or lying posture [5]. High levels of sedentary behaviour are associated with a reduction in muscle mass and strength [6], increased risk of falls [7] and even mortality[8]. Older post-stroke adults often engage in prolonged sedentary bouts, sitting for long uninterrupted periods, which poses a health risk independent of total sedentary time[9-11]. Recent studies have suggested that many interventions aimed at increasing physical activity and reducing sedentary behaviour during geriatric rehabilitation are ineffective. This may be attributable to the absence of behavioural change techniques within these interventions or to an insufficient level of intensity[12, 13]. As physical activity and functional performance are associated with reduced mortality and institutionalization after geriatric rehabilitation it is important to encourage these behaviours [14]. In addition, there is growing evidence that interrupting sedentary time with light activity is associated with better health indicators (e.g., cardiometabolic risk profile), which in turn could reduce the risk of recurrent stroke[15].

Most studies that have evaluated changes in sedentary behaviour during geriatric rehabilitation have concentrated on total sedentary time[13, 14]. However, as prolonged sedentary behaviour poses health risks regardless of total sedentary time, research has recently shifted focus to patterns of sedentary behaviour, as represented in the length and distribution of sedentary bouts[16]. The main advantage of this approach is its sensitivity when quantifying changes in sedentary behaviour, providing more robust insight into whether an intervention is effective[16, 17].

Finally, older adults recovering from stroke during geriatric rehabilitation are unlikely to be a homogeneous group and may actually harbour subgroups with divergent changes in physical activity and sedentary behaviour. Previously, three distinct subgroups showing different levels of physical activity and sedentary behaviour were identified in stroke survivors discharged to home , but no study to date has investigated whether comparable subgroups exist among older adults recovering from stroke during geriatric rehabilitation. Identifying subgroups may also contribute to the development of more effective, tailored interventions aimed at increasing physical activity and reducing prolonged sedentary bouts. Therefore, the primary goals of this study were to (1) quantify physical activity and sedentary behaviour, (2) assess any changes during geriatric rehabilitation, and (3) identify possible subgroups exhibiting distinct patterns of change in physical activity and sedentary behaviour during geriatric rehabilitation.

METHODS

Design & population

For this prospective cohort study, participants were recruited at four geriatric rehabilitation centres in the Netherlands between September 2020 and December 2022. All participants were older adults (≥ 65 years) recovering from stroke and undergoing geriatric rehabilitation. Eligible participants were able to comprehend and sign the informed consent, were able to walk and were capable of understanding and performing simple tasks. Participants were excluded if they were medically unstable. All participants gave written informed consent. The study protocol received a waiver of consent from the Utrecht medical ethical review committee (METC number: 20–462/C). Data were collected by physiotherapists and transferred to the researchers as anonymized data untraceable to any individual person.

Assessments

Baseline characteristics assessed upon admission comprised age, sex, body mass index (BMI), time since stroke, type of stroke and hemiparetic side. The following assessments were registered at both admission and discharge: Activities of Daily Living functioning (ADL) were measured using the Barthel index (range 0-20, higher scores indicate a better ADL performance)[18] , while balance was assessed using the Trunk Control Test (range 0-100, assesses trunk motor performance, consisting of three movement items and unsupported sitting)[19] . Ambulation mobility was evaluated using Functional Ambulation Categories (ranges from 0: non-functional walking to 5: independent walking outside)[20] and the USER subscale 'mobility', which consists of seven items (sitting, standing, transfers, indoor walking, outdoor walking, climbing stairs, wheelchair riding). Each item is scored on a 6-point scale (0-5) reflecting different grades of independence, use of aids and difficulty [21]. Balance was assessed every three weeks using the Berg Balance scale (range,0-56, higher scores indicate a better balance)[22] .

Movement variables

In addition to clinical instruments, physical activity and sedentary behaviour were quantified using an inertial measurement unit (IMU) (manufactured by Aemics b.v. Oldenzaal, The Netherlands). The IMU consisted of a triaxial accelerometer and gyroscope, which was placed above the lateral ankle. Movement variables included in this study were mainly derived from previous studies on this topic[16] and are described in further detail in Box 1.

Box 1. Types of movement variables

Movement variables	
Steps	Total steps per 2 days (mean steps/ 2 days)
Light activities	Time spent in light activities (mean hours/ 2 days)
Moderate activities	Time spent in moderate activities (mean hours/ 2 days)
Sedentary behaviour variables	
Sedentary behaviour	A minimal duration of 1 minute or higher in consecutive lying or sitting (mean hours/2 days)
Pattern of sedentary behaviour variables	
Sedentary bouts	A continuous period of sedentary time, with a minimal length of at least one minute (mean number bouts/ 2 days)
Sedentary breaks	The period between two sedentary bouts. An interruption in sedentary behaviour, such as standing or walking, with a minimal duration of 1 minute (mean number breaks/ 2 days)
Half-life bout duration (W50%)	A weighted median bout duration in which the bout duration above and below half of all sedentary time is accumulated. Provides a good indication of centrality given the distribution of bout length (minutes)[17, 23]
Alpha	A scaling parameter that provides an indication of the distribution of sedentary bouts. A lower alpha indicates that sedentary time largely accumulates in long bouts (unit-less variable)[23]
Gini Index	A standardised statistic for comparing patterns of accumulation. This coefficient ranges from 0 to 1. A G index of 1 indicates that all of the sedentary time is attributable to a very small proportion of the longest sedentary bouts. Conversely a G = 0 indicates that all sedentary bouts length contribute equally to the total sedentary time[23]

Data collection & wear time

Data were collected in the first week of admission (T0) to rehabilitation. Subsequent data collection (T1 to T3) occurred every third consecutive week, thus three, six-, and nine-weeks post-stroke. Patients were instructed to wear the IMU on their ankle during the day for two consecutive days in each measurement period. As we aimed to capture the majority of daily activities, we included measurements lasting at least 10 hours per day, as recommended[24]. Additionally, measurements were restricted to 7AM and 11PM to avoid sleep periods.

Statistical analysis

Normality of data was tested using the Shapiro-Wilk test. Differences between patient characteristics and movement variables were evaluated using one-way ANOVA for normally distributed data and are presented as means with standard deviations (±). The Kruskal-Wallis test was used for non-normally distributed data, which are presented as medians with interquartile ranges (IQR). Statistical analyses were performed using SPSS 25.0.

To assess the degree of change of physical activity and sedentary behaviour during geriatric rehabilitation, we analysed data from patients with at least one measurement on both admission and discharge. We then conducted a one-way ANOVA for normally distributed data and the Kruskal-Wallis test for non-normally distributed data to determine whether there was a significant difference in movement variables (described in Box 1) between admission and discharge. If the data exhibited a normal distribution at one measurement point and a non-normal distribution at another, the Mann-Whitney U test was used.

In order to identify groups with different patterns of change in physical activity, sedentary behaviour and sedentary behaviour patterns during geriatric rehabilitation, a principal component analysis (PCA) was performed to reduce the number of dimensions of the included movement variables (described in Box 1) while maintaining maximum information[25]. Prior to analysis, the Keiser-Meyer-Olkin (KMO) measure was used to assess the suitability of the overall PCA model. Individual movement variables with at least one correlation coefficient greater than 0.3 and a (KMO) measure greater than 0.6 were included in the PCA (Statistics, 2015). Components with eigenvalue ≥1 were used for extraction. The extracted components on admission and discharge were plotted to gain insight into the viability of identifying subgroups, based on the degree of change during geriatric rehabilitation.

RESULTS

Of the 79 eligible patients, 53 had at least two IMU measurements of 10 hours and were included in the study. Patient characteristics are described in detail in Table 1. Among the 53 patients, 42 had both admission and discharge measurements and could be included in the analysis of assessments and movement variables between admission and discharge.

Table 1. Baseline general characteristics (Mean ± SD, Median (IQR))

Characteristics	All patients (n = 53)	Admission – discharge* (n = 42)
Age (y)	77.7 ± 9.9	76.6 ± 9.9
Sex, male (%)	28 (52%)	22 (52%)
BMI (kg/m2)	25.9 (21.5 – 28.0)	24.7 (22.6 – 28.0)
Type of stroke		
Ischemic	43 (80%)	33 (79%)
Haemorrhagic	10 (18%)	8 (19%)
Subarachnoid	1 (2%)	1 (2%)
Hemiparetic side		
Left	25 (46%)	19 (45%)
Right	18 (33%)	13 (31%)
Both sides	2 (4%)	2 (4%)
Other	9 (17%)	8 (19%)
Time since stroke (days)	16.0 (12 –20)	15.0 (12 –21)
Length of stay rehabilitation (days)	35.0 (26.6 – 62.0)	35.5 (27.2 – 61.5)
Barthel Index	11.7 ± 4.4	11.7 ± 4.2
Berg Balance scale	37 (22.5 – 48.0)	38.0 (22.0 – 49.3)
Trunk Control Test	100 (87 – 100)	100 (93.5 – 100)
Functional ambulation classification	8 (15%)	6 (14%)
Non ambulatory (FAC 0)	22 (42%)	16 (37%)
Dependent (FAC 1-3)	20 (38%)	17 (40%)
Independent (FAC 4-5)		
USER mobility	17.1 ± 8.9	16.4 ± 8.4

*Patients in the group admission - discharge had an IMU measurement both at admission and discharge. USER: Utrecht Scale for Evaluation of Rehabilitation, FAC: Functional Ambulation Classification

Movement variables

Movement variables per measurement are described in Table 2. Visualization of percentage sedentary behaviour, light activities and moderate activities per measurement point are presented in Figure 1.

Table 2. Movement variables per measurement point (Mean(SD) ±, Median IQR)

	T0 n = 35	**T1** n = 25	**T2** n = 22	**T3** n = 17
Physical activity variables				
Steps (mean hours/2 days)	2068 (1191 – 2791)	1268 (868 – 3507)	2519 (1485 – 3345)	2561 (966 – 5053)
Light activities (mean hours/2 days)	2.5 (1.6 – 3.4)	3.3 (2.4 – 4.1)	2.7 (2.2 – 3.8)	2.9 (2.4 – 4.2)
Moderate activities (mean hours/2 days)	0.5 (0.3 – 0.8)	0.7 (0.3 – 1.1)	0.5 (0.4 – 1.1)	0.6 (0.2 – 1.0)
Sedentary behaviour variables				
Sedentary behaviour (mean hours/ 2 days)	10.2 (9.1 – 11.6)	9.6 (7.3 – 10.9)	11.0 (9.5 – 12.0)	10.8 (9.3 – 11.5)
Pattern of Sedentary behaviour variables				
Sedentary breaks (mean number breaks/ 2 days)	71.5 ± 28.2	86.4 ± 26.6	79.5 ± 23.9	79.9 ± 22.1
Half-life bout duration (mean minutes / 2 days)	25.0 (15.0 – 36.0)	21.0 (11.5 – 27.5)	22.0 (14.5 – 30.2)	21.0 (16.5 – 37.0)
Alpha	1.6 ± 0.1	1.6 ± 0.1	1.6 ± 0.1	1.6 ± 0.1
Gini	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1

*T0 – T3: first week of admission (T0). Subsequent data collections (T1 to T3) occurred every three consecutive weeks: three, six-, and nine-weeks post-stroke

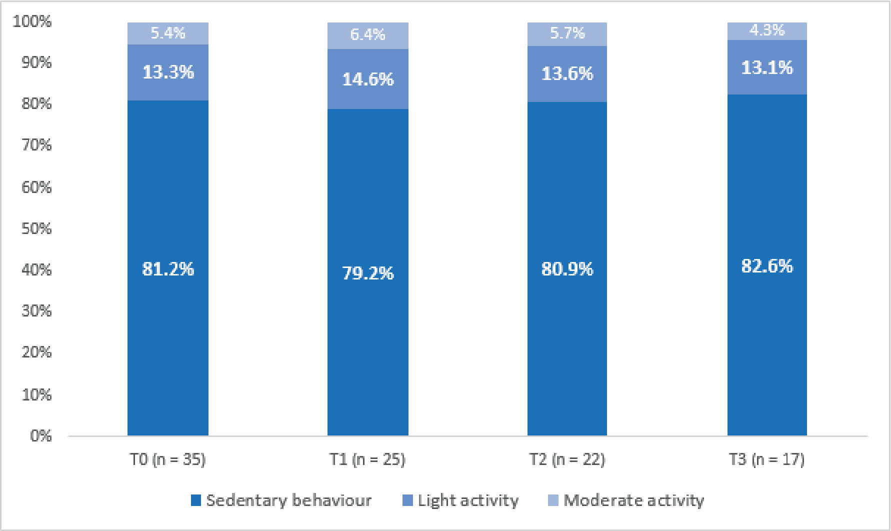


Figure 1. Levels of physical activity and sedentary behaviour
*T0 – T3: first week of admission (T0). Subsequent data collections (T1 to T3) occurred every three consecutive weeks: three, six-, and nine-weeks post-stroke

Change of SB and PA during geriatric rehabilitation

In total, 42 patients were included in the analysis regarding assessments and movement variables between admission and discharge. The mean wear time was 13.8 (SD 1.7) hours. Differences in assessments and movement variables between admission and discharge are shown in Table 3. Except for the Trunk Control test (P = 0.21), all assessments significantly improved between admission and discharge. Regarding movement variables, except for steps (P = 0.01) and moderate activities (P = 0.05), no significant change was observed in any movement variable or sedentary pattern variable.

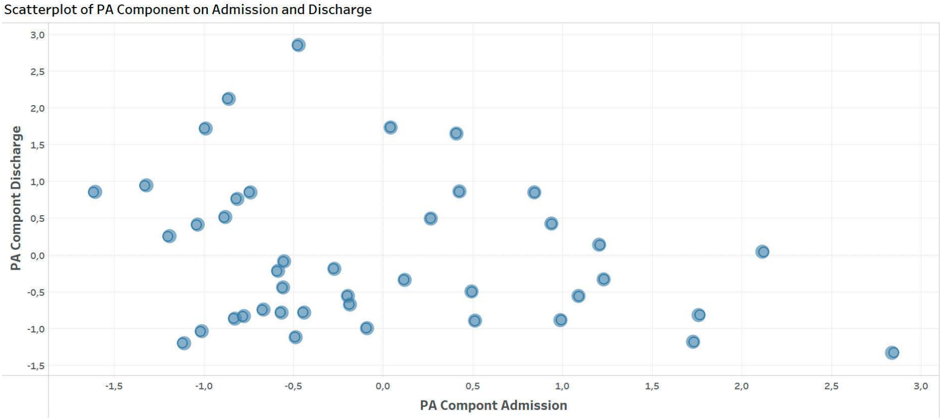
Table 3. Differences in assessments and movement variables between admission and discharge (Mean ±, Median (IQR))

n = 43	Admission	Discharge	P
Assessment			
Barthel index	11.5 ± 4.9	15 ± 7.1	0.01
Berg Balance scale	38 (22 – 38)	49.5 (41.8 – 54.0)	< 0.01
Trunk Control Test	100 (93 – 100)	100 (100 – 100)	0.21
Functional ambulation classification	3 (2 – 4)	5 (4 – 5)	< 0.01
USER mobility	17 ± 9.4	31 (25.5 – 34)	< 0.01
Physical activity variables			
Steps (mean steps/2 days)	1863 (919 - 2650)	2705 (1606-3968)	0.01
Light activities (mean hours/2 days)	2.6 (1.7 – 3.5)	3.0 (2.2 – 3.8)	0.27
Moderate activities (mean hours/2 days)	0.5 (0.2 – 0.9)	0.6 (0.3 – 1.0)	0.05
Sedentary behaviour variables			
Sedentary behaviour (mean hours/ 2 days)	10.3 (8.9 – 11.7)	10.6 (7.6 – 11.4)	0.46
Pattern of sedentary behaviour variables			
Sedentary breaks (mean number breaks/ 2 days)	75.1 ± 27.6	77.4 ± 25.9	0.69
Half-life bout duration (mean minutes / 2 days)	26.5 (14.8-35.3)	22.5 (14.5-30.3)	0.09
Alpha	1.6 ± 0.1	1.6 ± 0.9	0.94
Gini	0.5 ± 0.7	0.5 ± 0.7	0.15

USER: Utrecht Scale for Evaluation of Rehabilitation

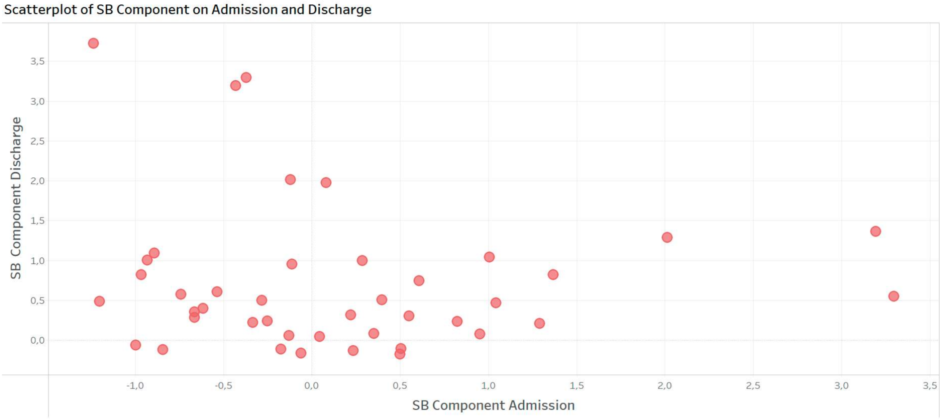
Patterns of change in PA and SB during geriatric rehabilitation

PCA revealed two components that had eigenvalues ≥ 1 and which together explained 66% of the total variance. The other 34% percent was distributed among eight components. The Kaiser–Meyer–Olkin for the complete PCA model was 0.74, indicating that the model was middling (Kaiser, 1974). The first component (accounting for 52% of variance) mostly included movement variables related to physical activity, and exhibited strong positive loadings for mean steps per two days, mean time spent in light activities, mean time spent in moderate activities, (more) sedentary breaks, and alpha (indicating sedentary time is largely spent in smaller bouts). Negative loadings were found for mean time spent in sedentary behaviour and mean time spent in sedentary behaviour, half-life bout duration (W50%). Higher values on the physical activity component indicate more active behaviour. The second component (14% variance) included movement variables related to sedentary behaviour, and showed strong positive loadings for mean time spent in sedentary behaviour, number of sedentary bouts ≥60 minutes per day , Gini Index, and half-life bout duration (W50%), with negative loadings for sedentary breaks. Higher values on the sedentary behaviour component indicate more sedentary behaviour. A plot of component loadings is visualized in Figure A1 (additional file 1). Scatterplots depicting the change in extracted physical activity and sedentary behaviour components between admission and discharge are shown in Figures 2 and 3. The scatterplots for both components depict a highly heterogeneous degree of change in physical activity and sedentary behaviour during geriatric rehabilitation, suggesting the absence of distinct subgroups based on degree of change.



PA Compont Admission and PA Compont Admission vs. PA Compont Discharge and PA Compont Discharge.

Figure 2. Difference in physical activity component scores between admission and discharge
PA: Physical activity. Higher values on the physical activity component indicate more active behaviour



SB Component Admission and SB Component Admission vs. SB Component Discharge and SB Component Discharge.

Figure 3. Difference in sedentary behaviour component scores between admission and discharge
SB: sedentary behaviour. Higher values on the sedentary behaviour component indicate more sedentary behaviour

DISCUSSION

Principal findings

In this study of older adults recovering from stroke during geriatric rehabilitation, our three main findings were: 1) in this group most waking hours were spent in sedentary behaviour, 2) there was little change in physical activity and no change in sedentary behaviour or patterns of sedentary behaviour despite improvements in functional performance, and 3) the degree of change in physical activity and sedentary behaviour was highly diverse, suggesting an absence of distinct subgroups.

Comparison with previous studies

Utilizing accelerometery data, we found that older adults recovering from stroke spend approximately 80% of their waking hours in sedentary behaviour. Although our study focused on older adults after stroke, prior studies investigating sedentary behaviour during geriatric rehabilitation have reported similar findings, indicating that older adults tend to allocate a significant portion of their time to sedentary behaviour. Rojer et al.[13] reported sedentary behaviour averaging 23 hours per day in older adults with various diagnoses, while Taylor et al.[26] documented a mean time of 22.3 hours per day spent in sedentary behaviour among older adults recovering from hip fracture. Both studies included sleep time in their classification of sedentary behaviour. By contrast, our study aimed to minimize the impact of sleep by restricting the analysis to data recorded between 7 AM and 11 PM. This difference in methodology unquestionably influenced our results, with the observed amount of sedentary behaviour in our study being notably lower than that reported in the studies of Rojer et al.[13] and Taylor et al.[26].

We observed significant differences in step count and moderate activities between admission and discharge, whereas no significant differences were found in light activities. As step counts incorporate both light and moderate-to-vigorous physical activity[27], a reasonable interpretation is that older adults recovering from stroke devoted a substantial proportion of steps to moderate rather than light activity. Finally, older adults recovering from stroke often demonstrate an improvement in walking speed throughout the rehabilitation process, achieving more steps in the same amount of time. This improvement in walking speed typically results in a classification of moderate physical activity due to increased amplitude and acceleration[28].

Although significant changes in functional performance were observed between admission and discharge, no differences were found in variables related to sedentary behaviour. While the improved functional performance typically achieved during geriatric rehabilitation might be expected to reduce sedentary behaviour, those recovering from stroke do not consistently exhibit the expected change in behaviour, suggesting that sedentary behaviour is not solely dependent on improvements in functional performance. Previously, researchers identified several barriers that may hamper improvements in sedentary behaviour such as fatigue, lack of knowledge, lack of motivation or fear of falling[29, 30]. Utilizing theory-based behaviour change techniques, coupled with a gradual stepwise approach that addresses prolonged sedentary behaviour, might potentially overcome these barriers[31]. Moreover, most multidisciplinary rehabilitation programs primarily emphasize the promotion of physical activity, with insufficient attention devoted to addressing and reducing sedentary behaviour[32].

To our knowledge, this is the first study to evaluate the degree of change in physical activity and sedentary behaviour among post-stroke older adults during inpatient geriatric rehabilitation. We found highly heterogeneous changes in physical activity and sedentary behaviour during geriatric rehabilitation, with significant variation between individuals, particularly in terms of physical activity, and to a lesser extent, sedentary behaviour. These results support the observed differences between admission and discharge, which were characterized by small changes in physical activity and no changes in sedentary behaviour or patterns of sedentary behaviour.

Strength and limitations

A strength of this study was the use of an IMU to objectively assess physical activity, sedentary behaviour and the pattern of sedentary behaviour, with positioning at the ankle facilitating accurate assessment of posture and transitions. However, while data were only included if patients wore the IMU for at least 10 hours during 2 days, this time period is a potential limitation, particularly regarding variables related to patterns of sedentary behaviour, where we observed little variability. While excluding data between 23:00 p.m. and 7:00 a.m. likely eliminated most sleep data, precisely differentiating sedentary behaviour from sleep was another limitation that may have impacted our results. Lastly, the small sample size may limit the generalizability of the results to the broader population of older stroke survivors in geriatric rehabilitation.

Implications for clinical practice & future research

One important conclusion that can be drawn from the current study is that each patient should be individually assessed at multiple time points when deploying interventions aimed at increasing physical activity and reducing sedentary behaviour. Accurate quantification of physical activity and sedentary behaviour through utilization of wearable sensors can aid understanding of each patient's unique digital phenotype[33], and facilitate the development of rehabilitation interventions tailored to improve physical activity and reduce sedentary behaviour.

CONCLUSION

In geriatric rehabilitation, older adults recovering from stroke devote a considerable amount of time to sedentary behaviour. Despite improvements in functional performance and physical activity, sedentary behaviour and patterns of sedentary behaviour did not change during geriatric rehabilitation. Furthermore, the degree of change in physical activity and sedentary behaviour during geriatric rehabilitation is highly diverse, particularly in physical activity and, to a lesser extent, sedentary behaviour.

We therefore recommend that multidisciplinary rehabilitation programs place greater emphasis on sedentary behaviour, not only though promotion of physical activity, but also through interventions aimed at reducing sedentary behaviour. These interventions should include use of wearable sensors to accurately quantify physical activity and sedentary behaviour, allowing interventions to be tailored to each patient's unique digital phenotype, and should also incorporate theory-based behaviour change techniques.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol received a waiver of consent from the Utrecht medical ethical review committee (METC number: 20–462/C). All participants gave written informed consent. The study was performed in accordance with the Declaration of Helsinki.

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DISCLOSURE STATEMENT

The authors declared no potential conflicts of interest.

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DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX

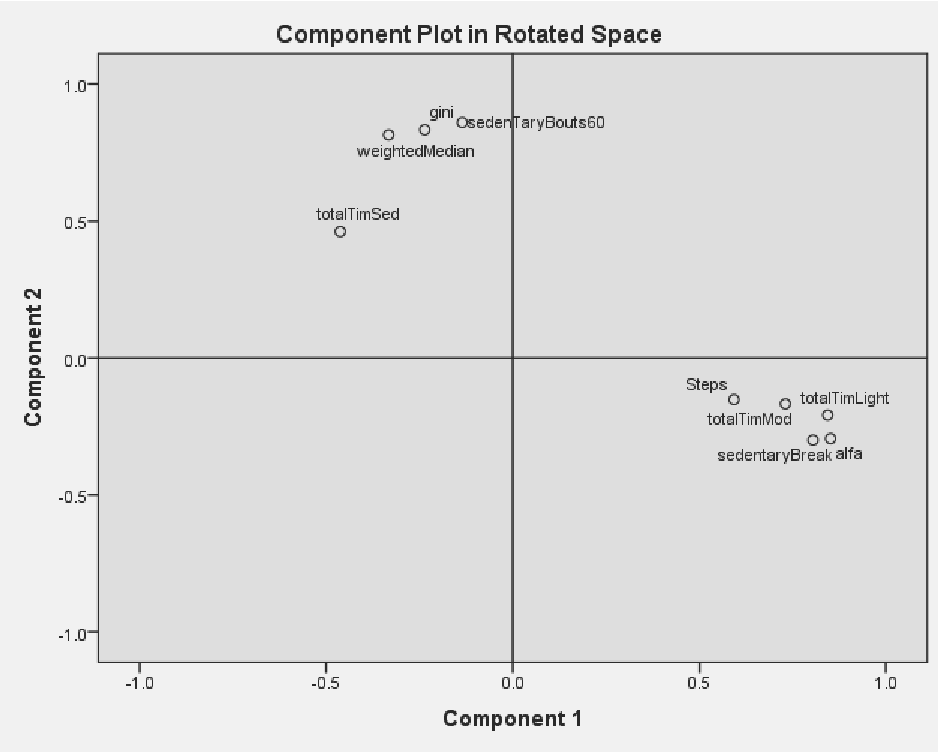
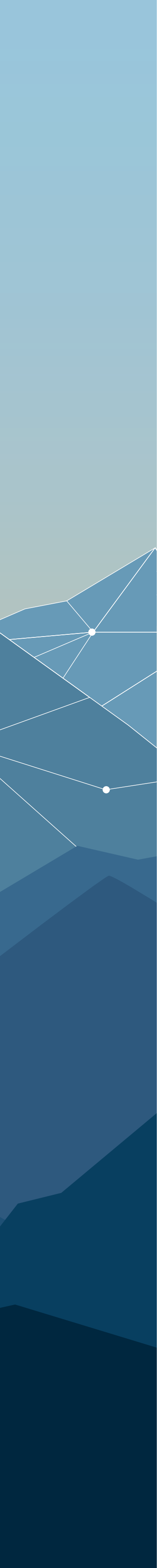


Figure A1: Loadings of the variables included in the principal component.



7

Movement Patterns in Older Adults Recovering From Hip Fracture

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ABSTRACT

Background

The aim of this study was to quantify physical activity and sedentary behaviour in older adults recovering from hip fracture, and to identify groups based on movement patterns.

Methods

In this cross-sectional cohort study, older adults (≥ 70 years) were included three months after surgery for proximal femoral fracture. Patients received an accelerometer for 7 days. Demographics and outcomes related to physical function, mobility, cognitive functions, quality of life and hip fracture were assessed.

Results

In total, 43 patients with sufficient accelerometer wear time were included. Across all groups, participants engaged in very low levels of physical activity, spending an average of 11 hours per day in prolonged sedentary behaviour.

Conclusions

Based on the extracted components from a principal component analysis, three groups with substantial differences in levels of physical activity and sedentary behaviour could be distinguished.

Keywords: Geriatric rehabilitation, physical activity, sedentary behaviour, accelerometer

INTRODUCTION

Hip fractures are an increasingly frequent consequence of falls in older adults and are becoming a significant concern. It is estimated that 30-60% of older adults who suffer a hip fracture experience permanent limitation to mobility or to their general level of independence[1].

Previous studies suggest that older adults recovering from a hip fracture undertake few physical activities and exhibit sedentary behaviour over prolonged daytime periods[2-7]. High levels of sedentary behaviour are associated with a reduction in muscle mass and strength[8], increased risk of falls[9], and even mortality[10]. Reducing sedentary behaviour and encouraging regular physical activities can help preserve an acceptable level of mobility and independence amongst older adults, and is especially important amongst older adults recovering from a hip fracture, since activity also increases the likelihood of recovery[11].

The first step to overcoming this problem is a better understanding of physical activity and sedentary behaviour. Physical activity refers to any body movement that raises energy expenditure above resting levels and is often categorized by intensity[12]. Sedentary behaviour is defined as behaviour resulting in energy expenditure ≤1.5 metabolic equivalents (METs) while in a sitting, reclining or lying posture[13]. Although physical activity and sedentary behaviour share some attributes, each should be considered a distinct domain. However, an increase in physical activity does not necessarily result in a reduction of sedentary behaviour[14]. For example, an older adult recovering from hip fracture might receive 30 minutes of therapy during the morning, but spend the rest of the day sitting. In recent times, the use of wearable activity sensors such as accelerometers has made it possible to obtain a reliable, objective representation of physical activity and sedentary behaviour[15, 16]. Nonetheless, it is important to properly assess and interpret accelerometer measurements, an issue that is particularly challenging in the case of sedentary behaviour as there are numerous ways, ranging from simple to complex, to assess this behaviour[17]. Recent literature supports a focus on the pattern of accumulation of sedentary behaviour, the main benefit of which is sensitive quantification of (changes in) sedentary behaviour[17, 18].

A second important step to help improve recovery after hip fracture is the identification of subgroups of older adults defined by levels of physical activity and sedentary behaviour. This is important because it enables us to provide tailored interventions that are likely to be more effective in improving the chance of recovery[19].

Therefore, the aims of this study were (1) to quantify physical activity and sedentary behaviour using an accelerometer, and (2) to identify groups based on movement patterns and correlate functional and mental characteristics in older adults recovering from hip fracture.

METHODS

Design & population

This study was part of the inception cohort-based study HIP CARE (Hip fractures: Inventarisation of Prognostic factors and their Contribution towArds Rehabilitation in older pErsons) (NTR NL7491). The goal of the HIP CARE study was to determine functional recovery, quality of life and healthcare use during the first year after a hip fracture and was initiated in 2018[20]. HIPCARE study participants are older adults (≥70 years) who in most cases were admitted to geriatric rehabilitation facilities in the Netherlands with a proximal femoral fracture. This is a single- center study in which patients are followed from one single hospital, to multiple regional geriatric rehabilitation facilities and home. Patients with high-energy trauma or pathological fractures were excluded.

In the current cross-sectional cohort study, Between January 2019 and March 2020, a selection of eligible patients of the HIPCARE cohort received an accelerometer for 7 days after an outpatient check-up three months after surgery. The goal was to obtain descriptive insights in the activity of the independent mobile patients of the HIPCARE cohort included.

Patients were instructed to wear the accelerometer on their waist 24 hours per day for seven consecutive days. For the reliable estimation of movement variables we only included patients who wore the accelerometer for at least 13 hours for a minimum of two days[21]. As the accelerometer could not clearly distinguish between sleeping and sedentary behaviour, accelerometer data between 23:00 PM and 7:00 AM were excluded to avoid misclassification of sedentary behaviour as sleep.

Assessments

Baseline characteristics were assessed during admission for surgery and comprised age, sex and body mass index (BMI), as well as general health status using the American Society of Anesthesiologists classification (ASA)[22]. The following assessments were registered during the outpatient check-up three months after surgery. Cognition was evaluated using the 6-Item Cognitive Impairment Test (range 0-28, lower scores indicate better cognitive functioning)[23]. Activities of Daily Living functioning was measured using the Katz Index of Independence in Activities of Daily Living (range, 0–6, higher scores indicate better ADL functioning)[24]. Mobility was assessed using the The Parker Mobility Score (TPM, range, 0–9, higher scores indicate better mobility)[25], Short Physical Performance Battery Living (SPPB, range, 0–12, higher scores indicate better lower extremity)[26], Functional Ambulation Classification (FAC, Ranges from 0: non-functional walking to 5: independent walking outside)[27] and Timed Up & Go test (TUG, lower scores indicate better mobility)[28]. Fear of falling was evaluated using the Falls Efficacy Scale International (FES, range 16-64, higher scores indicate greater fear of falling)[29]. Evaluation of hip fracture was assessed using the Harris Hip Score (HHS), which is a disease-specific measure for measuring outcomes after hip arthroplasty and includes the domains pain, function, deformity and range of motion (range 0 – 100, higher scores indicate better functioning)[30]. Quality of life was measured using the Dutch version of EuroQol (EQ-5D-5L) and the Visual Analogue Scale of EuroQol (EQ-5D-5L VAS)[31].

Movement variables were measured using the Dynaport MoveMonitor (Dynaport MoveMonitor, McRoberts BV, The Hague, The Netherlands), which is an accelerometer that records acceleration in a triaxial direction. Based on the measured accelerations, the DynaPort MoveMonitor classifies three postures (lying down, sitting and standing) and four movements (walking, cycling, climbing stairs and shuffling). Physical activity is quantified as movement intensity (average body acceleration during a specific activity), which can be subdivided into the activity levels Light, Moderate or Vigorous, based on metabolic equivalents (METs.)[32]. Movement variables included in this study were mainly derived from a recent review on this topic[17] and are described in further detail in box 1.

Box 1. Types of movement variables

Physical activity variables	
Steps	Total steps per day (mean steps/day)
Light activities	Time spent in light activities below 3 METs (mean hours/day) [32]
Moderate activities	Time spent in moderate activities above or equal to 3 METs and below 6 METs (mean hours/day) [32]
Vigorous activities	Time spent in vigorous activities above or equal to 6 METs (mean minutes/day) [32]
Sedentary behaviour variables	
Sedentary behaviour	A minimal duration of 1 minute in consecutive lying or sitting (mean hours/day)
Sedentary bouts ≥60 minutes per day	Time spent in sedentary bouts (uninterrupted periods of sitting and lying down) equal or above 60 minutes. Provides an indication of time spent in prolonged sedentary behaviour (mean hours/2 days)
Half-life bout duration (W50%)	A weighted median bout duration in which the bout duration above and below half of all sedentary time is accumulated. Provides a good indication of centrality given the distribution of bout length (minutes) [18, 33]
Alpha	A scaling parameter that provides an indication of the distribution of sedentary bouts. A lower alpha indicates that sedentary time is largely accumulated in long bouts (unit-less variable) [33]

Statistical analysis

Principal component analysis

In preparation for the cluster analyses, a principal component analysis (PCA) was performed to reduce the number of dimensions of the included movement variables described in Box 1 while maintaining maximum information[34]. Movement variables were standardized using z-scores. Prior to analysis the Keiser-Meyer-Olkin (KMO) measure was used to assess the suitability of the overall PCA model. Individual movement variables with at least one correlation coefficient greater than 0.3 and a (KMO) measure greater than 0.6 were included in the PCA[35]. Components with eigenvalues ≥1 were used for extraction. A Pearson's product-moment correlation was run to assess the relationship between the extracted components.

Cluster analysis

'Components' extracted from the PCA were used to identify different movement pattern groups using k-means clustering. Due to the exploratory nature of the present study the optimal number of clusters was determined using Silhouette analysis[36].

Normality of data was tested using the Shapiro-Wilk test. Differences between patient characteristics and movement variables were evaluated using One-Way ANOVA for normally distributed data and are presented as means with standard deviations (±).

The Kruskal-Wallis test was used for non-normally distributed data and is presented as medians with interquartile range (IQR). Baseline data and assessments outcomes thee months after surgery were compared for all patients included in the HIPCARE study, and for groups identified through cluster analysis. Data were analyzed with SPSS version 25.0.

Physical activity levels over one day were visualized in multiple series line graphs (Microsoft Excel) for individual clusters of each group's mean percentage activity for each 60-minute period.

RESULTS

Fifty-six eligible patients agreed to additional data collection three months after surgery, which was 27% of patients from the original HIPCARE study between January 219 and March 2020. Forty-three patients had sufficient accelerometer wear time of two days or more and were included in the analysis. Patient's characteristics are described in detail in Table 1. The median (IQR) age of patients was 81 (IQR 75-89), and 29 patients (67%) were female. Regarding patient's fractures, 22 (51%) had a femoral neck fracture, 19 (44%) had a pertrochanteric femoral fracture and 2 (6%) had a subtrochanteric fracture. Surgical treatments included osteosynthesis/internal fixation (29 patients, 67%) or a prosthesis/arthroplasty treatment (14 patients, 33%).

Except for age (75 vs. 81, P = <0.01) and TPM (5.8 vs 5.7 P = .02) there were no significant differences at baseline between patients included in the current study and patients in the overall HIPCARE study regarding demographics (sex, P = .34; BMI, P = .59; ASA, P = .82; post-operative discharge location, P =.14) and assessments three months after surgery regarding mobility (FAC, P = .09; TUG, P = .21), fear of falling (FES, P = .90), physical function (KATZ-ADL, P = .23; SPPB, P = .83), hip fracture (HHS, P = .45), cognitive function (CIT6, P = .09) or quality of life (EQ-5D-5L, P = .43; EQ-5D-5L VAS, P = .23).

Table 1. Patient characteristics (Mean ±, Median IQR)

	Baseline	3 months after surgery
Age (y)	81 (75-88)	
Sex, female (%)	29 (67%)	
BMI (kg/m2)	24.0 ± 3.0	
Comorbidity (ASA)	2 (2–3)	
Time since fracture (days)		92.2 ± 6.8
Post-operative discharge location		
Home	9 (21%)	
Geriatric rehabilitation	34 (79%)	
Length of stay rehabilitation (days)	48 (42-66)	
Current level of received care		
Independent		41 (96%)
Unknown		2 (4%)

BMI: body mass index, ASA: American Society of Anesthesiologists classification

Movement patterns

PCA revealed two components that had eigenvalues ≥1, which together explained 71% of the total variance. The KMO for the complete PCA model was 0.74, indicating that the model was middling [37]. The first, sedentary behaviour component (accounting for 58% of variance) mostly included movement variables related to sedentary behaviour, with strong positive loadings of mean time spent in sedentary behaviour, mean time spent in sedentary bouts ≥60 minutes per day, half-life bout duration (W50%), mean time spent in light activities and negative loadings of mean steps per day, mean time spent in moderate activities and Alpha. Higher values in the sedentary behaviour component indicate more sedentary behaviour . The second, physical activity component (13% variance) included movement variables related to physical activity with strong positive loadings of mean steps per day, mean time spent in moderate activities, mean time spent in vigorous activities and negative loading of mean time spent in sedentary bouts ≥60 minutes per day. Higher values on the physical activity component indicate more active behaviour. Component loadings are described in additional file 1. Three groups could be identified through k-means clustering, and the mean silhouette score for all clusters was 0.54. A scatterplot of the clusters and components can be found in figure 1. Movement variables per group are presented in Table 2 and visualized in Figure 2.

Table 2. Movement variables per group (Mean ±, Median IQR)

	Group 1 (n = 17)	Group 2 (n =21)	Group 3 (n = 5)	Total	P
Steps	232.6 (32.6-623.1)	1786.2 (920-4319.9)	7392.5 (4242.2-7392.5)	1235.9 (387.4-3034.3)	<0.01[*§]
Sedentary behaviour	13.3 ± 0.7	10.5 ± 1.3	10.6 ± 1.5	11.6 ± 1.8	<0.01[§†]
Light activities	14.3 ± 0.7	12.9 ± 1.1	12.7 ± 0.8	13.4 ± 1.2	<0.01[*§]
Moderate activities	0.2 (0.1-0.4)	0.9 (0.4-1.4)	1.9 (1.4-2.1)	0.5 (0.2-1.2)	<0.01[*§]
Vigorous activities	0.3 (0.2-0.6)	0.4 (0.2-1.0)	3.8 (2.9-4.6)	0.4 (0.2-1.0)	<0.01[§†]
Sedentary bouts ≥60 minutes per day	24.0 (15.0-26.5)	8.0 (3.0-14.0)	4.0 (1.5-12.5)	13.0 (5.0-23.0)	<0.01[*§]
Half-life bout duration (W50%)	124.0 (92.5-162,5)	36.0 (30.5-60.5)	30.0 (22.5-42.5)	56.0 (32.0-104.0)	<0.01[*§]
Alpha	1.3 ± 0.1	1.5 ± 0.1	1.5 ± 0.0	1.4 ± 0.1	<0.01[*§]
Worn time	14.6 (14.1-13.8)	13.9 (13.3-14.6)	14.7 (14.1-15.2)	14.5 (13.7-13.8)	0.06
Sedentary behaviour component	1.0 ± 0.4	-0.8 ± 0.5	-0.0 ± 0.8	0.0 ± 1.0	<0.01[*§†]
Physical activity component	-0.4 ± 0.4	-0.3 ± 0.6	2.3 ± 0.5	0.0 ± 1.0	<0.01[*§†]

Group 1 (n = 17, 39.5% of all included patients) was characterized by a very low step count, a very low level of physical activity and a very high level of sedentary behaviour that was largely accumulated (long sedentary bouts).

Group 2 (n = 21, 48.8%) was characterized by a moderate step count, a low level of physical activity, and a high level of sedentary behaviour that was more evenly distributed across moderate sedentary bouts.

Group 3 (n = 5, 11.6%) was characterized by a high step count, a moderate level of physical activity and a moderate level of sedentary behaviour that was relatively evenly distributed across shorter sedentary bouts.

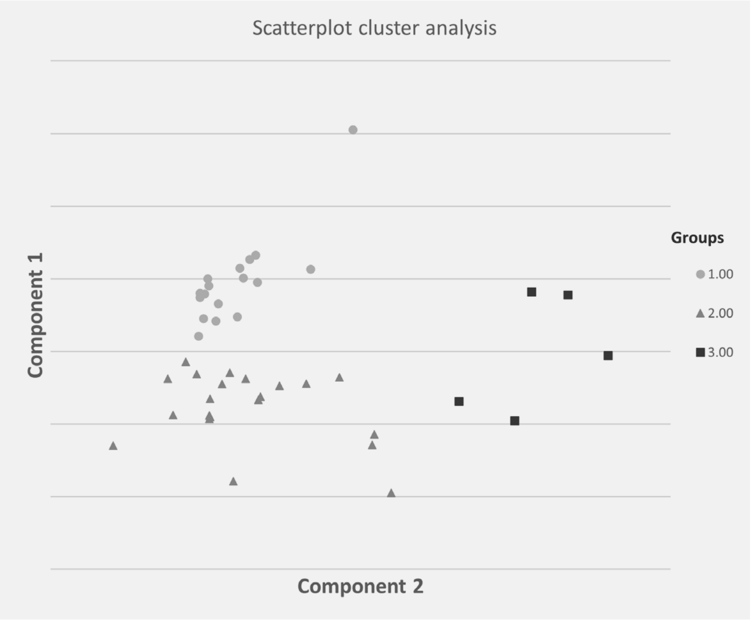

Figure 1. Graph in two dimensions presentation the two components per group. The sedentary behaviour component included movement variables related to sedentary behaviour, e.g., mean time spent in sedentary behaviour, mean time spent in sedentary bouts ≥60 minutes per day, half-life bout duration (W50%), Alpha and mean time spent in light activates. The physical activity component included movement variables related to physical activity: s mean steps per day, mean time spent in moderate activities and mean time spent in vigorous activities

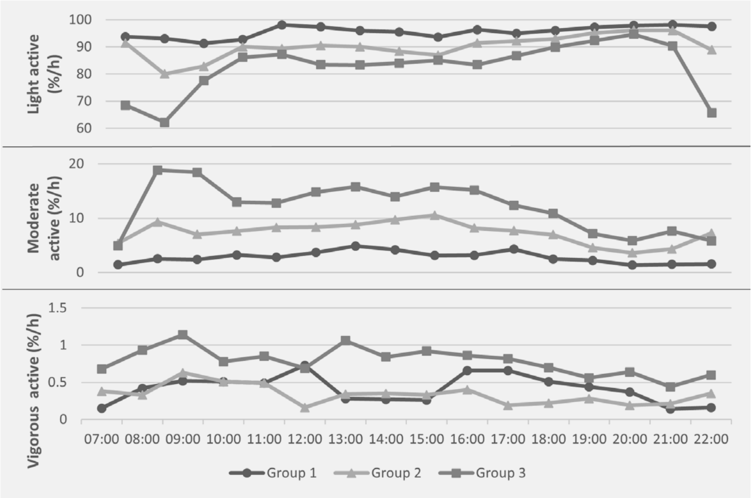

Figure 2. Physical activity levels for individual clusters mean percentage activity for each 60-minute period

Assessments

At baseline there were no significant differences between the groups regarding mobility (TPM, P = .22), physical function (KATZ-ADL, P = .29), quality of life (EQ-5D-5L, P = .79; EQ-5D-5L, VAS P = .26) or cognitive function (6CIT, P = .71). Due to the assessment on the day of the hip fracture the SPPB, TUG, FES, HHS and FAC could not be assessed at baseline. While the HHS differed significantly between all groups, there were no significant differences between the groups on specific items such as pain (HHS, domain pain; P = .06) or the locomotion functions of the hip joint (HHS, domain locomotion, P = .194) that could independently affect physical function. Furthermore, there was a small significant difference between all groups regarding type of surgical treatment (P =.03). There was no significant difference regarding post-operative discharge location (P = .07).

Assessments by group during the outpatient check-up three months after surgery are described in Table 3. Between all groups there were no differences regarding physical function (KATZ-ADL, P = .19) and cognitive function (6CIT, P = .95). Except for physical function (SPPB, P = .272), mobility (FAC, P = .60) and quality of life (EQ-5D-5L, P .28) all assessments were statistically significant different between group 1 and 2. Between group 1 and 3 all assessment were statistically different. Group 2 and 3 differed on mobility (FAC P = .27; TUG, P = .15; TPB, P = .79), fear of falling (FES, P = .37) and quality of life (EQ-5D-5L, P = .26; EQ-5D-5L, VAS P = .76).

Table 3. Patient assessments per group (Mean ±, Median IQR)

	Group 1 (n = 17)	Group 2 (n =21)	Group 3 (n = 5)	Total	*P*
Characteristics					
Age	81 (73- 90)	80 (73 – 90)	76 (73 – 80)	81 (75-88)	0.43
Sex, female (%)	12 (70%)	14 (67%)	3 (60%)	29 (67%)	0.90
Surgical treatment					0.03[†]
osteosynthesis/internal	11 (65%)	17 (81%)	1 (20%)	29	
prosthesis/arthroplasty	6 (35%)	4 (19%)	4 (20%)	14	
Post-operative discharge location					0.07
Home	3 (18%)	3 (14%)	3 (60%)	9	
Geriatric rehabilitation	14 (82%)	18 (86%)	2 (40%)	34	
Physical function					
KATZ – ADL	1.0 (0.0-2.0)	0.0 (0.0-1.5)	0.0 (0.0-0.0)	0.0 (0.0-2.0)	0.193
SPPB	5.4 ± 2.4	6.8 ± 3.0	10.8 ± 0.8	6.8 ± 3.1	<0.01[§†]
Hip fracture					
HHS	57.0 ± 12.3	66.7 ± 13.4	91.8 ± 5.8	66.4 ± 16.2	<0.01[*§†]

Mobility					
FAC	4.0 (3.0-4.0)	4.0 (4.0-4.5)	5.0 (4.0-5.0)	4.0 (4.0-4.0)	<0.01§
TUG	31.9 (23.1-35.1)	18.2 (13.1-23.1)	10.0 (8.5-11.2)	20.4 (12.2-35.0)	<0.01*§
TPM	4.0 (2.5-6.0)	6.0 (6.0-6.5)	9.0 (6.5-9.0)	6.0 (4.0-6.0)	<0.01*§
Fear of falling					
FES	12.0 (9.5-15.0)	9.0 (7.0-11.7)	7.0 (7.0-7.5)	9.5 (7.0-12.3)	<0.01*§
Cognitive function					
6CIT	2.0 (0.0-5.5)	2.0 (0.0-3.5)	2.0 (0.0-8.5)	2.0 (0.0-4.2)	0.948
Quality of life					
EQ-5D-5L	0.6 (0.4-0.7)	0.7 (0.6-0.8)	0.9 (0.8-0.9)	0.7 (0.6-0.8)	<0.01§
EQ-5D-5L VAS	60 (50.0-72.5)	75.0 (67.5-80.0)	80.0 (70.0-80.0)	70.0 (60.0-80.0)	0.02*§

KATZ-ADL = the Katz Index of Independence in Activities of Daily Living; SPPB = Short Physical Performance Battery Living; HHS = Harris Hip Score; FAC = Functional Ambulation Classification; TUG = Timed Up & Go test; TPM = The Parker Mobility Score; FES = Falls Efficacy Scale International; 6CIT = the 6-Item Cognitive Impairment Test; EQ-5D-5l = Dutch version of EuroQol; EQ-5D-5L VAS = Visual Analog Scale of EuroQol; IQR = interquartile range.

*Statistically significant differences between Groups 1 and 2. §Statistically significant differences between Groups 1 and 3. †Statistically significant differences between Groups 2 and 3.

DISCUSSION

Principal findings

In this study of older adults recovering from hip fracture three months after surgery, we identified three groups as defined by divergent levels of physical activity and sedentary behaviour. Our two main findings were: 1) across all groups older adults recovering from a hip fracture engaged in very low levels of physical activity and spent an average of 11 hours per day in prolonged sedentary behaviour; 2) based on movement patterns we identified three distinct groups with substantial differences in levels of physical activity and sedentary behaviour. Finally, no relationship was found between patient characteristics at baseline and movement patterns three months after surgery.

Comparison with previous studies

A unique aspect of our study was the evaluation of the pattern of sedentary behaviour. Our results suggest a clear difference between the three groups in terms of the pattern of sedentary behaviour, with group 1 showing a significantly higher proportion of long sedentary bouts. While previous studies have indicated that older adults recovering from a hip fracture tend to show very little physical activity and devote a significant amount of time to sedentary behaviour[2-4], none of these studies evaluated the pattern of sedentary behaviour. By interrupting prolonged sedentary periods, associated risks can be reduced, since prolonged sedentary behaviour poses a health risk independent of total sedentary time[38-40]. Evaluating patterns of sedentary behaviour may provide a better understanding of the effects of interventions designed to disrupt prolonged sedentary periods[18]. Furthermore during the early phase of rehabilitation planned and individually delivered comprehensive geriatric care in a geriatric hospital ward with particular focus on mobilization could improve physical activity and reduce sedentary behaviour[7]. However, the extent to which a reduction in sedentary behaviour reduces certain health risks remains to be determined[41].

Based on accelerometery we identified three groups of patients that differed regarding sedentary behaviour and the intensity of activity. When we compared the clinically assessed data associated with these three groups a clear pattern emerged: a low intensity of physical activity in combination with sedentary behaviour correlated with lower scores for mobility, physical function, hip fracture, and quality of life, as well as a greater fear of falling. However, no significant differences were found between group 2 and group 3 on assessments related to mobility. This may indicate that patients in group 2 are functionally able to increase physical activity and reduce sedentary behaviour, but did not display these movement patterns. Another potential explanation may be that current assessments related to mobility are unable to account for the difference in physical activity or sedentary behaviour between groups 2 and 3 Accelerometery-based observation of objective activity intensity and sedentary behaviour can thus provide early indications of a changing health status, allowing timely tailored interventions[19].

While the number of patients per group varied widely, group 3 was considerably smaller compared to groups 1 and 2. This distribution may be attributable to the cluster technique used, which does not allow for the size of clusters. Earlier studies of physical activity and sedentary behaviour variables that used similar clustering techniques also reported uneven distributions of patients per group, these studies also found that the smallest group consisted of the most physically active and least sedentary patients[42, 43].

We found no relation between patient characteristics at baseline and factors including pain, locomotion functions of the hip and movement patterns. However, we did observe a significant difference in terms of type of surgical treatment. In group 3, relatively more patients were treated by prosthesis/arthroplasty compared to osteosynthesis/internal fixation. Previous studies reported that patients after hip fracture who were treated by osteosynthesis/internal fixation had a higher reoperation rate, higher long-term mortality and lower quality of life after four months, compared with patients treated by prosthesis/arthroplasty[44, 45]. Furthermore, although we found no significant difference in post-operative discharge location, we observed that the number of patients discharged to geriatric rehabilitation in group 3 was relatively lower than in groups 1 and 2. This may indicate that patients in group 3 had better health status post-operatively and did not need geriatric rehabilitation. As the number of patients in group 3 is small, it is not possible at this time to draw a clear conclusion as to whether the difference in surgical treatment and discharge location has an effect on the movement patterns found. Finally, the differences found could potentially be explained by *'confounding by indication'*: the choice of surgical procedure is not random but related to the complexity of the fracture injury.

Nevertheless, other factors besides physical components likely impact the intensity of physical activity and sedentary behaviour. Previous qualitative research identified several barriers that can constrain engagement in physical activities and encourage sedentary behaviour, such as fear of falling, lack of motivation, fatigue, lack of time or lack of knowledge[46-49]. Theory-based behaviour change techniques, in combination with a stepwise approach that begins by targeting prolonged sedentary bouts, might help lower these barriers[14, 50].

In our study 'light activity' was defined as time spent in all activities below 3 METs. This meant that 'sedentary behaviour' also included all light activities. Other studies that have examined light activities in older adults recovering from a hip fracture chose other cut off points for levels of activity, which resulted in the exclusion of activities related to sedentary behaviour[2, 4]. This difference in classification method may have impacted our results, as the amount of light activity in our study was significantly higher than in comparable studies.

Finally, of the two components from the PCA, component one consisted almost entirely of variables related to sedentary behaviour, while component two consisted of physical activity variables. This might indicate that physical activity and sedentary behaviour are not interdependent, suggesting that both can be influenced independently to achieve improvements in health status[14, 51].

Strengths and limitations

A strength of this study was the use of an accelerometer and a strict data inclusion protocol in which we only used data from patients who wore the accelerometer for at least 13 hours for a minimum of two days. This provided an objective, accurate and reliable assessment of physical activity and sedentary behaviour. Another strength was the comprehensive description of all groups in terms of physical activity, sedentary behaviour and other assessments. Through PCA and K-means clustering we obtained a particularly good picture of a sub-group of older physically very inactive adults who therefore might have a higher risk of further functional decline. While we were able to objectively assess sedentary behaviour using an accelerometer, our protocol did not allow us to distinguish between sedentary behaviour in a sleeping or awake state. Although exclusion of data between 23:00 PM and 7:00 AM likely included the bulk of sleep data, our ability to accurately distinguish sedentary behaviour from sleep was nevertheless limited and may have influenced our results. This approach was chosen because including night sleep as 'sedentary behaviour' would have diluted relative activity and thus reduced sensitivity to discriminate groups based on activity. Furthermore, during this study, we did not record whether patients also received physical therapy during the accelerometer wearing period. This may have some effect on the results found, leading to a slight overestimation of the physical activity measures. Another limitation was the small sample size, partly because we had a strict inclusion protocol for the sensor data. We did not perform a sample size calculation prior to the study as the current research question was secondary in the HIPCARE study. However, this did limit the inclusion of movement variables in the PCA. Finally, no significant differences were found at baseline between the current participants and those included in the HIPCARE study.

CONCLUSIONS

Our primary conclusion is that older adults recovering from a hip fracture indeed engage in very low levels of physical activity and spend prolonged periods of time in sedentary behaviour. Secondly, based on actual movement patterns recorded by a wearable accelerometer, three distinct groups of older adults recovering from a hip fracture could be distinguished, each with distinct levels of intensity of physical activity and temporal sedentary behaviour. Thirdly, within these three groups a clear association was found between a low intensity of physical activity in combination with long sedentary periods and lower scores for mobility, physical function, hip fracture and quality of life, as well as a greater fear of falling. Finally, we argue that evaluation of the pattern of sedentary behaviour is essential when assessing the effectiveness of interventions aimed at reducing sedentary behaviour.

Future research should focus on determining the level of reduction in sedentary behaviour required to lower health risks. Classification of sedentary behaviour should exclude sleep periods and light activities. Furthermore, multidisciplinary rehabilitation programs need to place greater emphasis on the contribution of sedentary behaviour by not only promoting physical activity, but by also including interventions designed to reduce sedentary behaviour. Those interventions should be tailored and include theory-based behaviour change techniques, in combination with a stepwise approach that starts by targeting prolonged sedentary bouts.

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LIST OF ABBREVIATIONS

ASA: American Society of Anesthesiologists classification

BMI: Body Mass Index

HHS: Harris Hip Score

HIP CARE: Hip fractures: Inventarisation of Prognostic factors and Their Contribution towArds Rehabilitation in older pErsons

KMO: Keiser-Meyer-Olkin

METs: Metabolic equivalents

PCA: Principal component analysis

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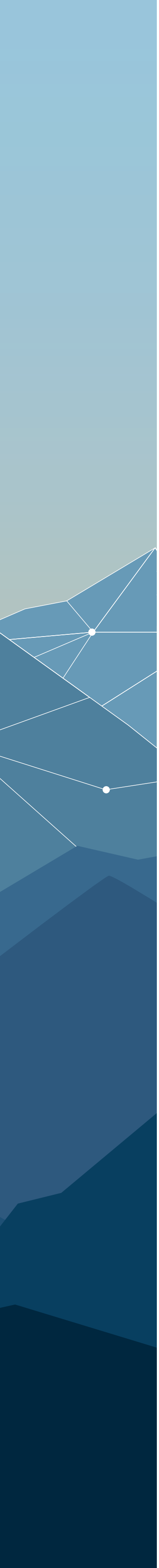
APPENDIX

Table 1. Loading of variables in the two components indicating for Sedentary Behaviour (1) and Physical Activity (2)

	Sedentary component	**Physical activity Component**
Steps	-0.52	0.744
Sedentary behaviour	0.92	
Light activities	0.69	
Moderate activities	-0.58	0.74
Vigorous activities		0.90
Sedentary bouts ≥60 minutes per day	0.60	-0.36
Half-life bout duration (W50%)	0.76	
Alpha	-0.80	



8

General discussion

GENERAL DISCUSSION

eHealth has the potential to address current challenges and improve rehabilitation outcomes in geriatric rehabilitation. However, the adoption of eHealth in geriatric rehabilitation is still limited. The overall aim this thesis was to create a foundation for evidence & practice-based eHealth in geriatric rehabilitation and to investigate one of the most promising eHealth types; wearable sensors.. To achieve this goal, the following research questions were addressed:

1. Which elements are important for effective use of eHealth in Geriatric rehabilitation?
2. To which extent can wearable sensors enhance the prediction of functional recovery and monitoring of individual progress in geriatric rehabilitation?

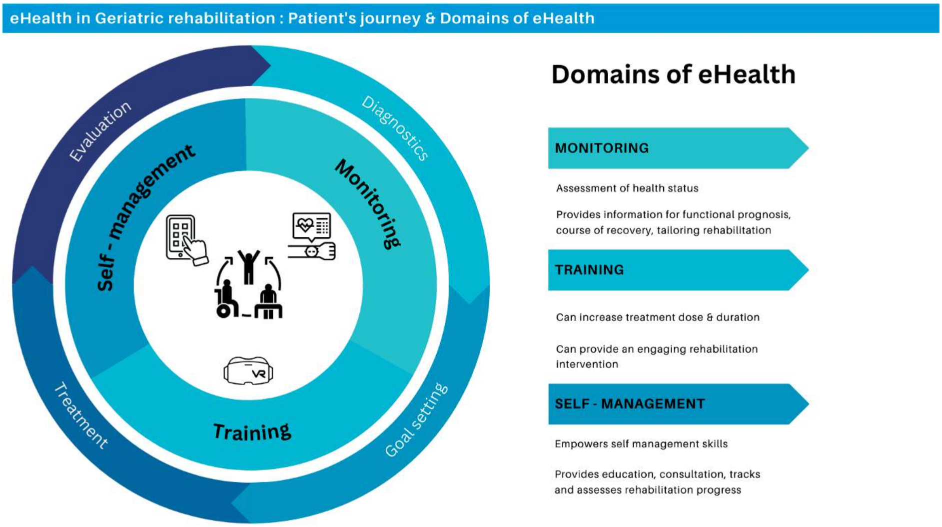
This chapter summarizes and discusses the main findings of this thesis and the methodological choices made. Finally, implications and recommendations for future research, current practice and education are presented.

Part 1: Elements for effective use of eHealth in geriatric rehabilitation

Chapter 2 describes a systematic review that assessed the evidence on effectiveness, feasibility and usability of eHealth in geriatric rehabilitation. A search of seven databases identified in a total of 40 studies. The results showed that in most studies eHealth interventions were at least as effective as non-eHealth interventions. Simple eHealth interventions were more likely to be feasible in geriatric rehabilitation, especially, in combination with another non-eHealth intervention, also referred to as *blended care*. However, very few studies included outcomes related to usability, which hinders the effective use of eHealth.

In **chapter 3** a survey was used to explore the experiences and needs of healthcare professionals in an international multicenter cross-sectional study. A total of 513 healthcare professionals from 16 countries participated. Although half of the participants had some experience with using eHealth in geriatric rehabilitation, only 10% integrated eHealth into their daily practice. Several important barriers to the use or implementation of eHealth were identified, including: insufficient resources, lack of an organization-wide implementation strategy and lack of knowledge. Participants expressed an urgent need for reliable information on how to effectively identify, use and evaluate eHealth.

Based on the results of our systematic review and international survey an international consensus study on eHealth in geriatric rehabilitation was conducted (**Chapter 4**). In total 80 participants from 10 countries took part in a two-round Delphi procedure. Participants reached consensus on 26 statements: 3 on the use of eHealth, 5 on the domains of eHealth and 18 on the topic of scientific evaluation of eHealth. The results of the study highlighted the need for a more specific description of eHealth in geriatric rehabilitation. To this end, a model has been created to provide clear and reliable eHealth information in an accessible format for patients and healthcare providers on the use and domains of eHealth in geriatric rehabilitation. The model is displayed in figure 1. The model utilizes a patient journey framework to highlight domains in which eHealth could offer added value at various stages of the rehabilitation process. By incorporating a patient journey into the final model, it aims to assist both patients and healthcare professionals in geriatric rehabilitation in understanding the appropriate use and timing of eHealth interventions within their context.



Assessment of health status

Provides information for functional prognosis, course of recovery, tailoring rehabilitation

Can increase treatment dose & duration

Can provide an engaging rehabilitation intervention

Empowers self management skills

Provides education, consultation, tracks and assesses rehabilitation progress

Figure 1: Model Patient’s journey & domains of eHealth

Part 2. Wearable sensors to enhance geriatric rehabilitation

In the prospective cohort study (**Chapter 5**), objectively measured postural sway assessed by an inertial measurement unit (IMU) was used to determine whether it could improve the prediction of functional recovery at discharge in combination with, or compared to, the Utrecht Scale for Evaluation of Rehabilitation (USER). In total 71 patients recovering from stroke were included. This study showed that combining postural sway data as measured by an IMU with USER data has the potential to improve the prediction of functional recovery at discharge compared to USER data alone. However, the postural sway assessment was too difficult for non- ambulatory patients and therefore not feasible for this subgroup.

In **chapter 6,** an IMU was used to quantify physical activity, sedentary behaviour and their degree of change during geriatric rehabilitation in 53 older adults recovering from stroke. During rehabilitation, older adults recovering from stroke improved in functional performance but at the same time spent most waking hours in sedentary behavior. During their stay they showed little change in physical activity and almost no change in sedentary behaviour or the pattern of sedentary behaviour. The degree of change during rehabilitation in physical activity and sedentary behaviour was highly diverse.

In **chapter 7,** we quantified physical activity and sedentary behavior in hip fracture patients three months after geriatric rehabilitation and identified groups based on their movement patterns . Three groups were identified with distinct levels of physical activity and sedentary behaviour. In all groups, older adults recovering from hip fracture had in low levels of physical activity and spent most of their time in prolonged sedentary behaviour.

Opportunities & challenges for eHealth in geriatric rehabilitation

In summary, eHealth offers several opportunities in geriatric rehabilitation: eHealth can potentially improve rehabilitation outcomes for older patients receiving geriatric rehabilitation (**chapter 2**), eHealth has the potential to improve the prediction of functional recovery at discharge (**chapter 5**) and is capable to quantify physical activity and sedentary behaviour (**chapters 6 & 7**). However, the main challenge is the low adoption of eHealth in geriatric rehabilitation (**chapter 3**). To increase the adoption of eHealth, there are several important barriers to overcome such as: the lack of usability outcomes (**chapter 2**), the lack of an organization-wide implementation strategy and the urgent need for healthcare professionals for reliable information on how to effectively identify, use and evaluate eHealth (**chapter 3**) . In the following section, we will take a deep dive into a few topics that can help overcome the current challenges of eHealth in geriatric rehabilitation and explore some of the future opportunities.

Keep it simple

Our findings from our systematic review and international survey (**chapter 2 & 3**) both suggest that simple eHealth interventions are more likely to be successful in adopting eHealth in geriatric rehabilitation. There is no clear definition of 'simple eHealth'. In our perspective, these interventions are primarily characterized by their ease of use for both patients and professionals, as well as their ease of integration into clinical workflow. The two main reasons that eHealth in geriatric rehabilitation should be simple are: 1) older adults in geriatric rehabilitation often suffer from cognitive or physical impairments[1, 2], which can present difficulties in learning digital skills [3] where simple eHealth interventions are more likely to be feasible. 2) Ease of use and ease of integration are key facilitators for the implementation of eHealth interventions[4-6]. This is especially important for healthcare professionals, while willing to make greater use of eHealth (**chapter 3**), often have a limited acceptance of eHealth[7-9]. The use of eHealth often changes their workflow, and the lack of integration of eHealth into their daily workflow is a barrier to the adoption of eHealth[4-6, 10]. Healthcare professionals are important stakeholders in the adoption of eHealth, not only are they unmissable in the development and implementation of eHealth[11] , but they can also act as "promotors" of eHealth interventions to their patients[12].

Tailoring

Tailoring is a strategy that involves developing personalized advice, information or customizing the design and functionality of an eHealth intervention to more effectively meet the specific needs and preferences of an individual[13]. Compared to nontailored eHealth interventions, tailored eHealth interventions are often more effective and accepted[14, 15].In our international survey (**chapter 3**) 276 out of 513 (54%) of participants indicated that inadequate tailoring to the older population in geriatric rehabilitation was a barrier to the use or implementation of eHealth. While eHealth is often poorly tailored to older adults, tailoring should be a prerequisite to ensure that eHealth interventions maximize the likelihood of successful adoption in geriatric rehabilitation. Taking into account factors such as physical or cognitive impairments, experience with eHealth, and health literacy of older adults[16, 17]. Furthermore, it's important for healthcare- professionals and organizations to identify which eHealth interventions are 'simple' and 'fit' their local context. Evaluation frameworks for eHealth interventions, such as the European Committee for Standardization (CEN) - International Standardization Organization (ISO)/ Technical Specifications (TS) 82304-2[18], can help healthcare professionals and organizations to make informed judgements and ultimately promote the adoption of eHealth in geriatric rehabilitation.

Tailored rehabilitation

In geriatric rehabilitation there is no one-size-fits-all approach. Rehabilitation is often tailored based on the individual patient, taking into account factors such as diagnosis, multimorbidity and geriatric syndromes, as well as individual rehabilitation goals. Therefore, developing interventions that account for the unique characteristics of each individual patient is an important step to provide tailored rehabilitation and is becoming an emerging topic in the field of rehabilitation[19, 20]. The use of eHealth in geriatric rehabilitation enables opportunities to tailor rehabilitation interventions to the individual older adult. For example, combining objectively measured postural sway assessed by an IMU with the USER improved the prediction of functional recovery at discharge compared to the USER alone (**chapter 5**). This approach integrates of data from different International Classification of Functioning, Disability and Health (ICF) domains the IMU assesses the Body Functions and Structures domain, while the USER evaluates the Activities domain. By combining technology-based data with clinical scales, it offers insights across multiple ICF domains, creating possibilities for a unique digital phenotype for each patient. Digital phenotyping is defined as the *"moment-by-moment quantification of the individual-level human phenotype in situ using data from personal digital devices"* [21]. The data captured can even detect slight changes in a patient's condition, offering more precise and sensitive data, referred to as digital biomarkers[22]. Digital phenotyping not only makes it possible to tailor rehabilitation based on digital biomarkers derived from wearable sensors in combination with clinical scales, but also to increase patients' involvement in their own rehabilitation journey by presenting the data as personalized feedback[23].

Couch-less rehabilitation

Using wearable sensors, we were able to quantify sedentary behaviour during and after geriatric rehabilitation in hip fracture- and stroke patients. In both studies we observed that these patients spent most of their time in prolonged sedentary behaviour (**chapter 6 & 7**). Even if older adults improved in functional performance during rehabilitation, there was little change in physical activity and no change in sedentary behavior (**chapter 6**). While assessing sedentary behaviour is a relatively new field in geriatric rehabilitation, current evidence indicates that prolonged sedentary behavior is linked to a decline in muscle mass and strength, a higher risk of falls, and even increased mortality[24-26]. For the first time, the World Health Organization (WHO) included specific recommendations on the associations between sedentary behaviour and health outcomes in their recent guidelines on physical activity and sedentary behaviour[27]. This highlights the importance of reducing sedentary behaviour. Current geriatric rehabilitation programs typically focus on encouraging physical activity and improving functional performance, but they often neglect the importance of reducing prolonged sedentary behavior. The

WHO guidelines recommend that older adults should 1) limit the amount of time spent being sedentary and replace it with physical activity of any intensity and 2) should aim to do more than the recommended levels of moderate to vigorous intensity physical activity to offset the detrimental effects of prolonged sedentary behaviour[27]. For patients admitted to geriatric rehabilitation, this recommendation should be tailored to each individual's capacity and functionality. The goal is to adopt a stepwise approach to reduce sedentary behavior, where patients with lower capacity and functionality initially focus on breaking up longer periods of sedentary time before progressing to replace sedentary behavior with physical activity[28] . This contrasts with what might be termed as an "elevator" approach, in which patients are encouraged to replace sedentary behavior with moderate to vigorous physical activity immediately. The stepwise or "staircase" approach (figure 2) may enhance the success of reducing sedentary behavior in older adults admitted to geriatric rehabilitation since they often have physical impairments and lower intrinsic capacity.

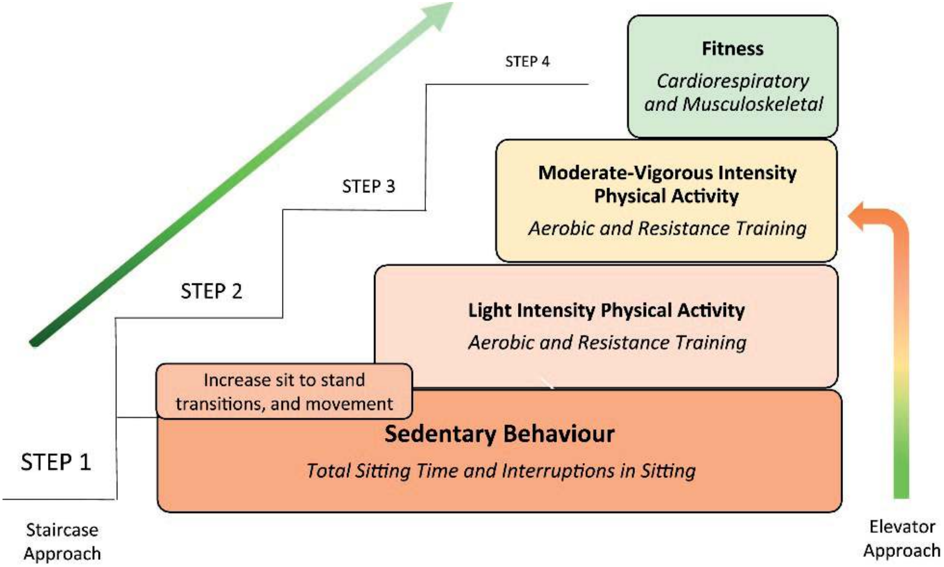


Figure 2. A staircase versus elevator approach to promoting physical activity and reducing sedentary behaviour. Figure obtained from Dogra et al[28].

Methodological considerations

Study population

While there is international consensus on the definition of geriatric rehabilitation, the operationalization of geriatric rehabilitation in clinical practise can vary widely per country. In some countries, while geriatric rehabilitation services exist, they are not formally recognized as geriatric rehabilitation [29, 30]. This variability in the delivery of geriatric rehabilitation was evident in our systematic review (**Chapter 2**), where only 9 of 40 included studies (23%) was conducted in a specific geriatric rehabilitation setting. To ensure that the included study group accurately represents current practices in geriatric rehabilitation, we only included studies that examined older adults with a mean age of ≥70 years and patients with a chronic disease with no acute functional decline were excluded. However, only a minority of the included studies in the review reported data if the included patients admitted to a rehabilitation service was based on a chronic disease or (sub-)acute functional decline. In our international survey (**Chapter 3**) and consensus study (**Chapter 4**) the majority of participants were recruited from countries within Europe. The primary reason for the unequal sample sizes across countries is that the distribution of the surveys was conducted by members of the European Geriatric Medical Society's (EuGMS) 'Special Interest Group'(SIG) for Geriatric Rehabilitation, who acted as primary contacts in each country in both studies. In a way, it reflects that for research this network is effective in recruiting healthcare professionals working in geriatric rehabilitation across Europe[31]. However, for the studies mentioned above this poses challenges in determining whether the included study group truly represents the patient population in our systematic review (**Chapter 2**) or the healthcare professionals in our international survey (**Chapter 3**) and consensus study (**Chapter 4**) in geriatric rehabilitation, which may limit the generalizability of the results.

For the development and evaluation of eHealth interventions it is important to involve multiple stakeholders at the start of the process. One of the most important stakeholders are often the intended users themselves, which, in the context of this thesis, are older adults admitted to geriatric rehabilitation. As healthcare professionals play an essential role in the adoption of eHealth and in facilitating of eHealth interventions for older adults receiving geriatric rehabilitation, we focused on their perspectives in our international survey (**Chapter 3**) and consensus study (**Chapter 4**). A limitation of this thesis is that we did not include the perspectives of older adults, despite their role as end-users. This limitation may have influenced our findings in these two studies. In our international survey (**Chapter 3**), healthcare professionals indicated that the use of eHealth was significantly more complex for patients than for themselves. Previous research has shown that healthcare professionals may hold negative perceptions regarding older adults' ability to use eHealth[32]. It is possible that if older adults had been asked this question, they might have perceived eHealth as less complex than healthcare professionals assumed. Furthermore, in our consensus study (**chapter 4**), we developed a model for both older adults and healthcare professionals that outlines the use and domains of eHealth in geriatric rehabilitation in an easy-to-understand format. Given that older adults often have expectations of eHealth that might differ from its intended design—potentially resulting in a mismatch between their actual needs and the intended purpose of eHealth interventions—it remains unclear whether this model effectively supports their understanding of in geriatric rehabilitation.

Outcome measures

In our prospective cohort study (**chapter 5**), we used USER data to assess functional recovery in older adults recovering from stroke. The USER is a multidimensional observational instrument, which was specifically developed to assess progress during rehabilitation[33] and has demonstrated adequate clinometric properties for geriatric rehabilitation[34, 35]. In our prospective cohort study (**chapter 5**), we only used the mobility subscale of the USER, as it is most closely related to the postural sway assessed by the IMU. The use of the mobility subscale of the USER has some limitations: the mobility subscale does not fully capture the functional recovery of older adults recovering from stroke, which usually also includes other aspects such activities of daily living (ADL) function, instrumental activities of daily living I(ADL) function and participation[36]. Additionally, the USER is predominantly used in the Netherlands, making it difficult to compare results with other international studies.

In current geriatric rehabilitation practice, mobility and activities of daily living (ADL) function are often mostly used as primary outcomes. In recent years, participation has emerged as an increasingly recognized outcome as well[37]. Participation as a concept is complex, mainly because it is determined among various variables from the person, their social roles, and the environment[38]. In the cohort studies of this thesis, we did not include a outcome measure related to participation. Currently, there is no clear international consensus on which validated instrument is recommended to effectively capture the complexity of participation[39]. The Canadian Occupational Performance Measure (COPM)[40] might be a useful instrument to assess participation post-rehabilitation, which has been validated in geriatric rehabilitation[41].

Implications and recommendations

Based on the results of this thesis we outline implications and recommendations across three key topics: clinical practice, education, and research. Each topic is addressed individually below; but it's important to acknowledge their interconnectedness in order to establish a robust foundation for evidence- and practice-based eHealth in geriatric rehabilitation (figure 3).

Figure 3. interconnectedness in clinical practice, education, and research for evidence- and practice-based eHealth.

Clinical practice

One of the primary challenges for eHealth in current geriatric rehabilitation practice is its low adoption. Based on the findings of this thesis four key recommendations emerged that can help in address this issue in clinical practice: (1) eHealth in geriatric rehabilitation should be simple, tailored and blended, (2) Focus on eHealth interventions that can be used in the domains of monitoring, training and self-management, (3) Establish an organization-wide implementation strategy for eHealth, and (4) Provide specific eHealth information to patients and healthcare professionals. First, simple and tailored eHealth interventions which are integrated in care pathways have a higher chance to be effective, feasible and usable. Second, by focusing eHealth interventions on monitoring, education and self-management, it will contribute to a more consistent approach to implementation and evaluation of eHealth. Third, an organization-wide implementation strategy for eHealth that incorporates barriers (i.e. lack of knowledge, lack of time) and facilitators (i.e. availability of technical resources, digital support)[42]. To this end, the Hybrid Health Care Quality Assessment (HHQA)[43] can be utilized as a tool for improving the quality and integrating of eHealth current geriatric rehabilitation (figure 4). The HHQA enables organizations to identify areas for improvement even before the development of an implementation strategy. Fourth, our final model '*Patient's journey & domains of eHealth'* (figure 1) can serve as a guide for both patients and healthcare professionals in understanding the use of eHealth in geriatric rehabilitation.

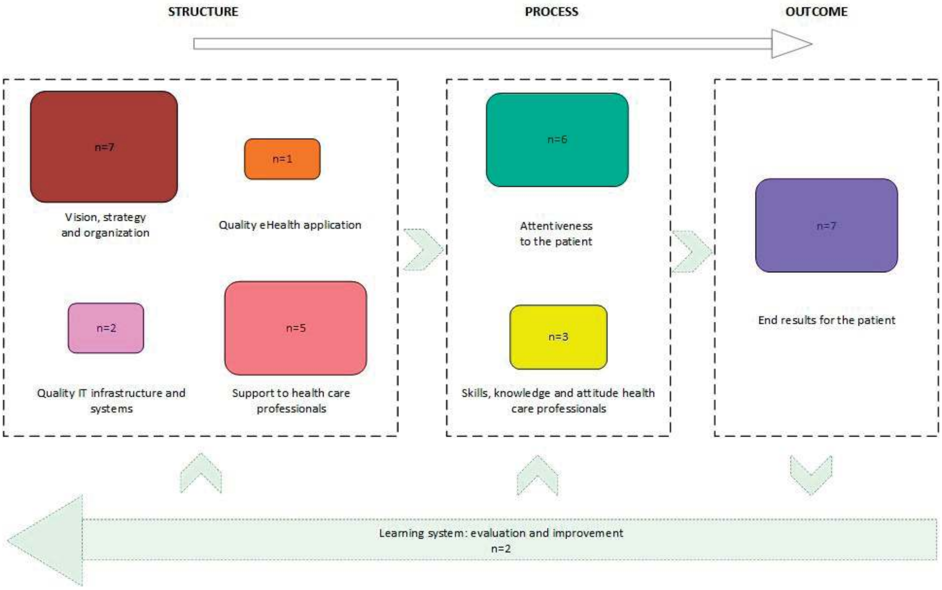


Figure 4. the Hybrid Health Care Quality Assessment (HHQA) model[43]

Education

Just as interpersonal collaboration is essential for maintaining high-quality care in geriatric rehabilitation[44], so is interprofessional education important for preparing healthcare professionals to effectively address complex issues within interprofessional teams[45]. Interprofessional education occurs when students from two or more professions learn about, from, and with each other to enable effective collaboration and improve health outcomes[46]. It should specifically address important eHealth topics such as: types of available eHealth interventions, methods for assessing, implementing and evaluating eHealth and strategies for tailoring them to varying levels of eHealth literacy in older adults[47]. These interprofessional teams should include students such as nurses (practitioners), doctors, physiotherapists, and occupational therapists. Additionally, they should incorporate students who bridge the gap between science, technology, and clinical practice, such as students in technical medicine. Technical medicine students follow a hybrid technical-medical curriculum and are trained to tailor technology use to patient specific conditions and needs[48]. This integration could help in promoting the exchange of knowledge between technology and clinical practice. The inclusion of technical medicine professionals should be considered not only in education but also in current practice of geriatric rehabilitation. Their expertise can help in improving the use of new or existing technology with patients, mitigate risks associated with technology use, and streamline clinical workflow[49]. Incorporating technical medicine professionals into Interprofessional teams in geriatric rehabilitation could ultimately facilitate the adoption and evaluation of eHealth in geriatric rehabilitation.

Research

In our consensus study (**Chapter 4**) we established consensus related to the evaluation of eHealth. Future studies should always include usability outcome domains and incorporating age-related outcomes such as cognition, physical ability and motivation, which is in line with the MOLD-US framework[16]. Furthermore, older adults in geriatric rehabilitation, along with healthcare professionals, should always be involved in the development and evaluation of eHealth. While it is advisable for older adults to participate in the evaluation and in the development of eHealth through co-creation, current evidence is inconclusive whether older adults involvement benefits acceptance or adoption of eHealth[50]. Therefore, this needs to be investigated further. As we did not include the opinions of older adults during the consensus study, despite developing a model specifically designed to help them understand the use and timing of eHealth in geriatric rehabilitation, it is essential that future studies validate this model with older adults to ensure it fits their needs.

Both studies in which we utilized an IMU to objectively measure human movement (**Chapters 5 & 6**) involved a relatively small sample size and focused exclusively on older adults recovering from stroke. While stroke is the leading diagnose that prompts admission to geriatric rehabilitation[30], it is essential for future research on this topic to include other diagnoses within geriatric rehabilitation, such as hip fracture. This inclusion will enhance the generalizability of the findings to a broader population of older individuals recovering from various conditions in geriatric rehabilitation.

Finally, with future studies we should gain more insight into movement patterns in and after geriatric rehabilitation within different diagnostic groups. During these studies, each patient should be assessed individually at multiple time points to better understand their unique digital phenotype. By gaining insight into each digital phonotype, this could facilitate tailored interventions to promote physical activity and reduce sedentary behaviour in geriatric rehabilitation. These interventions should adopt a step-wise approach that focuses on breaking up prolonged periods of sedentary behaviour. Preferably by replacing sedentary behaviour with (light) physical activity.

Epilogue – the case of Mr. Peters.

Mr. Peters, a 74-year-old stroke patient, is now in his third week of rehabilitation. This week, he starts using an accelerometer to track his physical activity and sedentary behavior. A mobile app provides daily insights into his movement and reminds him to stand if he sits for more than 60 minutes. He reviews the weekly results with his physical therapist, Jack.

While setting up the accelerometer, Jack received assistance from his new colleague, Sara, a technical physician. She helped him configure the device properly and integrate it into his daily routine. During Jack's weekly consultation with Mr. Peters, they reviewed the app data and noticed progress in his physical activity. As a result, they added extra exercises for Mr. Peters to do outside of therapy sessions, which helped him improve enough to return home just a week later.

Once home, Mr. Peters continues to receive weekly therapy from Jack—alternating between video communication one week and home visits the next. He still wears the accelerometer, and through the app, he can perform additional exercises and stay in touch with Jack between sessions. His rehabilitation goals now focus on resuming daily activities, like grocery shopping, cooking, and playing bridge with his friends.

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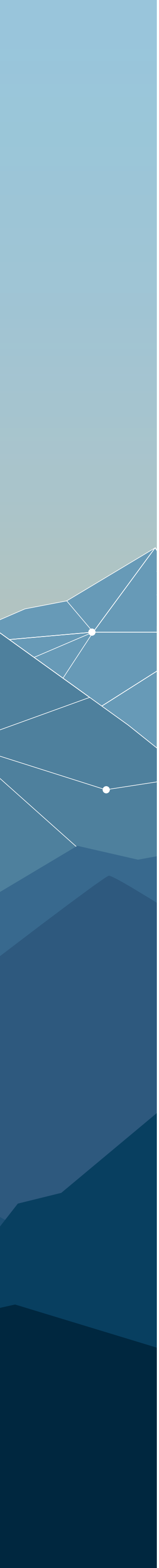


9

Summary

Samenvatting

Bibliography

Dankwoord

Curriculum Vitae

SUMMARY

Due to the rapid aging of the global population, the number of older adults suffering from age-related conditions such as frailty and multimorbidity is rising quickly. These individuals are more vulnerable to functional decline and face an increased risk of acute events such as strokes or falls.

After an acute event, geriatric rehabilitation enables older adults to regain their independence, preserve functional reserves, and maintain social participation. It follows an interdisciplinary approach, where various professionals collaborate to provide therapy tailored to individual rehabilitation goals. The rapid increase in frail older adults and the shortage of healthcare staff present significant challenges for geriatric rehabilitation. New strategies are needed to maintain the affordability, accessibility, and quality of geriatric rehabilitation. The use of eHealth has the potential to address these challenges by improving the quality and ensuring accessibility of geriatric rehabilitation.

eHealth can be defined as "*the use of digital information and communication to support and/or improve health and health care*". There are various types of eHealth interventions, ranging from relatively simple solutions like video communication and mobile apps to more advanced approaches such as robotics and virtual reality. While eHealth holds promises, the integration of eHealth in geriatric rehabilitation remains challenging. This is often due to scarce evidence of effective eHealth interventions, the complex and time-consuming implementation of eHealth.

This thesis describes the results of the EAGER study (EHeAlth in GEriatric Rehabilitation). The overall aim of the EAGER study is to create a foundation for evidence & practice-based eHealth in geriatric rehabilitation and to investigate a promising eHealth intervention; wearable sensors. In this thesis the following research questions were addressed:

1. Which elements are important for effective use of eHealth in Geriatric rehabilitation?
2. To which extent can wearable sensors enhance the prediction of functional recovery and monitoring of individual progress in geriatric rehabilitation?

Part 1: Elements for effective use of eHealth in geriatric rehabilitation

The first part of this thesis provides an overview of the current evidence on eHealth in geriatric rehabilitation, explores the experiences and needs of healthcare professionals, and establishes a consensus on its use and evaluation of eHealth in geriatric rehabilitation.

In **chapter 2** the current evidence on effectiveness, feasibility and usability of eHealth in geriatric rehabilitation was assessed with a systematic review. The search in seven different databases yielded 40 different studies. Results indicated that eHealth interventions in geriatric rehabilitation are at least as effective as non-eHealth interventions. All studies that included eHealth in combination with another non-eHealth intervention (blended care) reported positive rehabilitation outcomes. Simple eHealth interventions were more likely to be feasible for older adults receiving geriatric rehabilitation, while complex eHealth interventions such as robotics might only be feasible for a selective group of older adults. Limited evidence on the usability of eHealth, indicated that certain age-related barriers associated with cognitive or physical ability that led to difficulties in using eHealth.

Chapter 3 explored the experiences needs of healthcare professionals were in an international multicenter cross-sectional study. In total, 513 healthcare professionals working in geriatric rehabilitation from 16 countries participated. Over half of the participants had experience with eHealth; however, only 10% of all included professionals incorporated eHealth into their daily routines. Professionals indicated that the use of eHealth was often more complex for patients than for themselves Additionally, professionals expressed their needs for reliable information on suitable eHealth interventions for their local context and guidance on their implementation. Key barriers to integrating eHealth into daily practice included the lack of sufficient tailored eHealth interventions, limited availability of resources and the absence of an organization-wide implementation strategy.

Building on the findings from our systematic review and international survey, an international consensus study on eHealth in geriatric rehabilitation was conducted (**chapter 4**). A total of 80 participants from 10 countries participated in a two-round Delphi procedure. The participants included healthcare professionals who had experience of eHealth in geriatric rehabilitation. Consensus was reached on 26 statements: 3 regarding the use of eHealth, 5 on eHealth domains, and 18 on the scientific evaluation of eHealth. The results of this study underlined the need for a clear and specific definition of eHealth in geriatric rehabilitation. Therefore, a simple and accessible model was developed to provide a specific description of the use and domains of eHealth in geriatric rehabilitation. The model is displayed in figure 1. This model incorporates a patient journey and can therefore assist both patients and healthcare professionals in geriatric rehabilitation by helping them understand the appropriate use and timing of eHealth interventions within their specific context. Finally, reaching consensus on specific outcome domains, such as usability and age-related outcomes, for the evaluation of eHealth may ultimately promote a consistent approach to the scientific and safety evaluation of eHealth in geriatric rehabilitation.

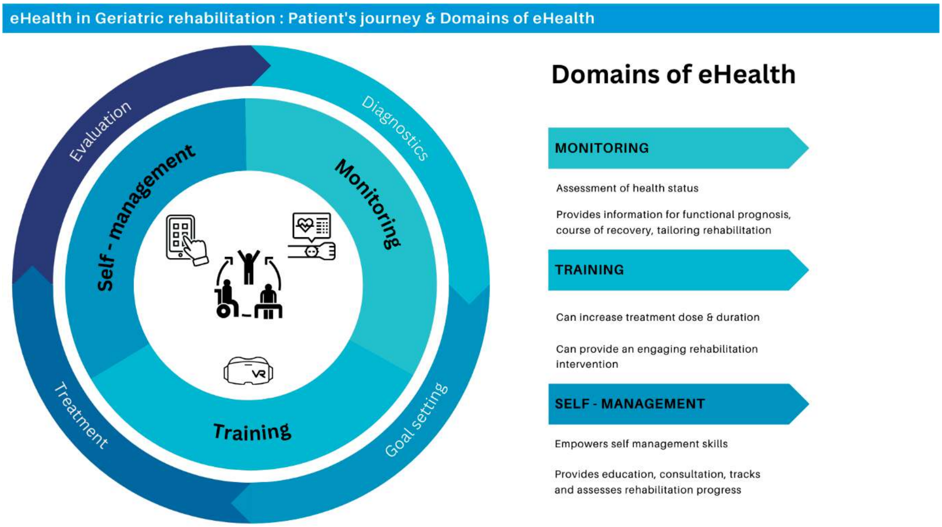


Figure 1. Patient's journey & domains of eHealth

Part 2: Wearable sensors to enhance geriatric rehabilitation

Part 2 of this thesis explores the application of wearable sensors in geriatric rehabilitation. It describes whether objectively measured postural sway enhances the prediction of functional recovery at discharge. Additionally, it describes the use of wearable sensors to quantify physical activity and sedentary behavior both during and after rehabilitation.

Chapter 5 describes the use of a inertial measurement unit (IMU) to assess postural sway to determine whether it could improve the prediction of functional recovery at discharge in combination with, or compared to, the Utrecht Scale for Evaluation of Rehabilitation (USER). A total of 71 patients recovering from stroke were included. Twelve of the 71 patients were unable to perform some of the balance conditions due to insufficient balance. To assess the predictive value for functional recovery at discharge, the explained variance was compared between three different regression models: one based on USER, one based on IMU measurements, and a combined model. Incorporation of postural sway in the combined regression model increased the explained variance compared to a model in which only USER was used to predict functional recovery at discharge. Based on these results, we can conclude that combining IMU-measured postural sway with USER data has the potential to improve functional recovery predictions at discharge. The assessment of postural sway was too challenging for non-ambulatory patients, limiting its feasibility for this subgroup.

In **chapter 6**, an IMU was used to quantify physical activity, sedentary behavior, and their changes during geriatric rehabilitation in 53 patients recovering from stroke. During rehabilitation, patients spent the majority of their waking hours in sedentary behaviour. Despite improvements in functional performance, there was minimal increase in physical activity and no significant changes in sedentary behaviour and the patterns of sedentary behaviour. In addition, the degree of change in physical activity and sedentary behaviour during geriatric rehabilitation varied considerably among individual patients, with greater variability observed in physical activity than in sedentary behavior.

Chapter 7 describes the results of a cross-sectional cohort study that quantified physical activity, sedentary behaviour and the patterns of sedentary behaviour in 43 patients recovering from hip fracture three months after geriatric rehabilitation. Results showed that older adults recovering form hip fracture engaged in very low levels in physical activity and spend prolonged periods in sedentary behaviour. Based on movement patters assessed by a wearable sensor, three groups could be distinguished, each characterized by different intensities of physical activity and sedentary behavior. Within these groups a clear association was found between a low intensity of physical activity in combination with long sedentary periods and lower scores for mobility, physical function, hip fracture and quality of life, as well as a greater fear of falling.

Conclusion

Based on the findings of this thesis, our primary conclusion is that eHealth holds potential to improving rehabilitation outcomes for older adults receiving geriatric rehabilitation. Blended and simple eHealth interventions are the most promising and feasible. Despite these potentials, the adoption of eHealth in geriatric rehabilitation is still limited. Key barriers need to be overcome, such as the lack of usability outcomes, the lack of an organization-wide implementation strategy and the urgent need for healthcare professionals for reliable information on how to effectively identify, use and evaluate eHealth. To this end our model '*Patient's journey & domains of eHealth*' (figure 1) can serve as a guide for both patients and healthcare professionals in understanding the use of eHealth in geriatric rehabilitation. Additionally, wearable sensors have proven to be capable of quantifying physical activity, sedentary behaviour and the patterns of sedentary in older adults during and after geriatric rehabilitation. Notably, this population engages in very low levels of physical activity and spends the majority of their waking hours in sedentary behaviour. Finally, The use of wearable sensors show potential in improving the prediction of functional recovery at discharge.

NEDERLANDSE SAMENVATTING

Door de snelle vergrijzing van de wereldbevolking neemt het aantal ouderen met leeftijdsgebonden aandoeningen, zoals kwetsbaarheid en multimorbiditeit, snel toe. Deze groep is kwetsbaarder voor functionele achteruitgang en loopt een verhoogd risico op acute gebeurtenissen, zoals een herseninfarct of een valincident.

Na een acute gebeurtenis ondersteund geriatrische revalidatie ouderen om hun zelfstandigheid te herwinnen, functionele reserves te behouden en sociale participatie te waarborgen. Dit gebeurt via een interdisciplinaire aanpak, waarbij verschillende professionals samenwerken om therapieën af te stemmen op de individuele revalidatiedoelen. De snelle toename van kwetsbare ouderen en het tekort aan zorgpersoneel vormen grote uitdagingen voor de geriatrische revalidatie. Nieuwe strategieën zijn nodig om de betaalbaarheid, toegankelijkheid en kwaliteit van deze zorg te waarborgen. Het gebruik van eHealth biedt hierin mogelijkheden door zowel de kwaliteit te verbeteren als de toegankelijkheid van geriatrische revalidatie te garanderen.

eHealth kan worden gedefinieerd als " *het gebruik van nieuwe informatie- en communicatietechnologieën, en met name Internet-technologie, om gezondheid en gezondheidszorg te ondersteunen of te verbeteren."* Er bestaan verschillende soorten eHealth-interventies, variërend van relatief eenvoudige oplossingen zoals videocommunicatie en mobiele apps tot geavanceerdere toepassingen zoals robotica en virtual reality. Hoewel eHealth veelbelovend is, blijft de integratie ervan in de geriatrische revalidatie een uitdaging. Dit komt vaak door het beperkte wetenschappelijke bewijs voor de effectiviteit van eHealth-interventies en de complexe, tijdrovende implementatie ervan.

Dit proefschrift beschrijft de resultaten van de EAGER-studie (EHeAlth in GEriatric Rehabilitation). Het algemene doel van de EAGER-studie is om een fundament te leggen voor wetenschappelijke- en praktijk gebaseerde eHealth in de geriatrische revalidatie en om een veelbelovende eHealth-interventie te onderzoeken: draagbare sensoren. In dit proefschrift werden de volgende onderzoeksvragen behandeld:

1. Welke elementen zijn belangrijk voor het effectieve gebruik van eHealth in de geriatrische revalidatie?
2. In hoeverre kunnen draagbare sensoren de voorspelling van functioneel herstel en het monitoren van individuele voortgang in de geriatrische revalidatie ondersteunen?

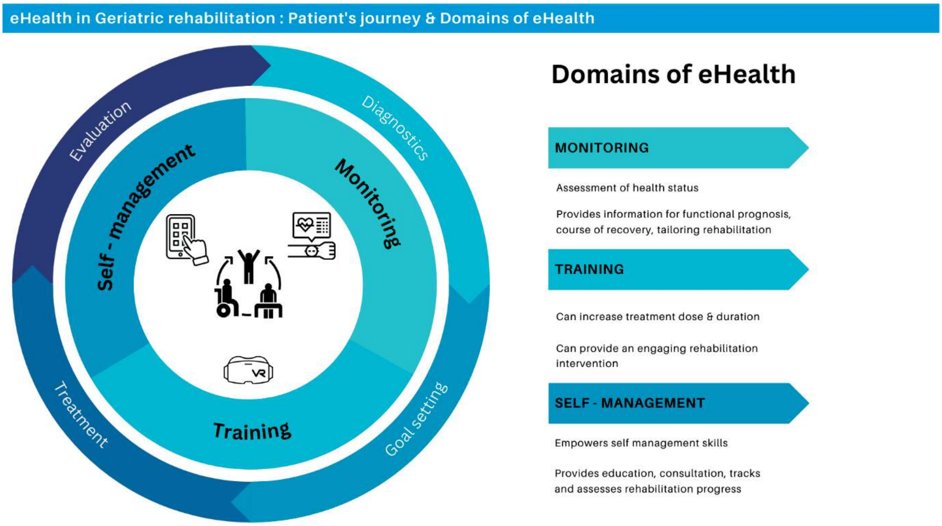
Deel 1: Elementen voor effectief gebruik van eHealth in de geriatrische revalidatie

Het eerste deel van dit proefschrift biedt een overzicht van het huidige bewijs over eHealth in de geriatrische revalidatie, onderzoekt de ervaringen en behoeften van zorgprofessionals en stelt een consensus vast over het gebruik en de evaluatie van eHealth in de geriatrische revalidatie

In **hoofdstuk 2** werd het huidige wetenschappelijke bewijs over de effectiviteit, haalbaarheid en bruikbaarheid van eHealth in de geriatrische revalidatie beoordeeld met een systematische review. De zoekopdracht in zeven verschillende databanken resulteerde in 40 verschillende studies. De resultaten gaven aan dat eHealth-interventies in de geriatrische revalidatie ten minste even effectief zijn als niet-eHealth-interventies. Alle studies die eHealth combineerden met een andere niet-eHealth-interventie (blended care) rapporteerden positieve revalidatie-uitkomsten. Eenvoudige eHealth-interventies bleken eerder haalbaar te zijn voor ouderen die geriatrische revalidatie ontvingen, terwijl complexe eHealth-interventies zoals robotica mogelijk alleen haalbaar zijn voor een selecte groep ouderen. Beperkt bewijs over de bruikbaarheid van eHealth gaf aan dat bepaalde leeftijdsgebonden barrières, gerelateerd aan cognitieve of fysieke beperkingen, leidden tot moeilijkheden bij het gebruik van eHealth.

Hoofdstuk 3 onderzocht de ervaringen en behoeften van zorgprofessionals in een internationale multicenter dwarsdoorsnede-onderzoek. In totaal namen 513 zorgprofessionals die werkzaam waren in de geriatrische revalidatie uit 16 verschillende landen deel. Meer dan de helft van de deelnemers had ervaring met eHealth; echter, slechts 10% van de geïncludeerde professionals verwerkte eHealth in hun dagelijkse routines. Zorgprofessionals gaven aan dat het gebruik van eHealth vaak complexer was voor patiënten dan voor henzelf. Daarnaast gaven ze aan behoefte te hebben aan betrouwbare informatie over geschikte eHealth-interventies voor hun lokale context en begeleiding bij de implementatie ervan. Belangrijke obstakels voor het integreren van eHealth in de dagelijkse praktijk waren het gebrek aan gepersonaliseerde eHealth-interventies, beperkte beschikbaarheid van middelen en het ontbreken van een organisatie brede implementatiestrategie.

Bouwend op de bevindingen uit onze systematische review en internationale enquête, werd een internationale consensusstudie over eHealth in de geriatrische revalidatie uitgevoerd (**hoofdstuk 4**). In totaal namen 80 deelnemers uit 10 landen deel aan een Delphi-procedure bestaande uit twee rondes. De deelnemers waren zorgprofessionals met ervaring in eHealth binnen de geriatrische revalidatie. Consensus werd bereikt over 26 stellingen: 3 over het gebruik van eHealth, 5 over eHealth-domeinen en 18 over de wetenschappelijke evaluatie van eHealth. De resultaten van deze studie benadrukten de behoefte aan een eenduidige en specifieke definitie van eHealth in de geriatrische revalidatie. Dit heeft geleid tot de ontwikkeling van een eenvoudig en toegankelijk model dat een specifieke beschrijving geeft van het gebruik en de domeinen van eHealth in de geriatrische revalidatie. Het model wordt weergegeven in figuur 1. Dit model bevat een patiëntreis en kan zowel patiënten als zorgprofessionals helpen door hen inzicht te geven in het juiste gebruik en de timing van eHealth-interventies binnen hun specifieke context. Ten slotte kan het bereiken van consensus over specifieke uitkomstdomeinen, zoals bruikbaarheid en leeftijd gerelateerde uitkomsten, voor de evaluatie van eHealth uiteindelijk bijdragen aan een consistente benadering van de wetenschappelijke en veiligheidsbeoordeling van eHealth in de geriatrische revalidatie.


eHealth in Geriatric rehabilitation : Patient's journey & Domains of eHealth

Domains of eHealth

MONITORING

Assessment of health status

Provides information for functional prognosis, course of recovery, tailoring rehabilitation

TRAINING

Can increase treatment dose & duration

Can provide an engaging rehabilitation intervention

SELF - MANAGEMENT

Empowers self management skills

Provides education, consultation, tracks and assesses rehabilitation progress

Figuur 1. Patiëntreis en domeinen van eHealth

Deel 2 Draagbare sensoren ter ondersteuning van geriatrische revalidatie

Het tweede deel van dit proefschrift onderzoekt de toepassing van draagbare sensoren in de geriatrische revalidatie. Het beschrijft in hoeverre objectief gemeten lichaamszwaai de voorspelling van functioneel herstel bij ontslag verbetert. Daarnaast wordt het gebruik van draagbare sensoren beschreven om fysieke activiteit en sedentair gedrag zowel tijdens als na de revalidatie te kwantificeren.

Hoofdstuk 5 beschrijft het gebruik van een inertial measurement unit (IMU) om lichaamszwaai te beoordelen en te onderzoeken of dit de voorspelling van functioneel herstel bij ontslag kan verbeteren, in combinatie met of in vergelijking met de Utrechtse Schaal voor de Evaluatie van Klinische Revalidatie (USER). In totaal werden 71 patiënten die herstelden van een herseninfarct of hersenbloeding geïncludeerd. Twaalf van de 71 patiënten waren niet in staat om bepaalde balanstesten uit te voeren vanwege onvoldoende evenwicht. Om de voorspellende waarde voor functioneel herstel bij ontslag te beoordelen, werd de verklaarde variantie vergeleken tussen drie verschillende regressiemodellen: één op basis van USER, één op basis van IMU-metingen en een gecombineerd model. De toevoeging van lichaamszwaai aan het gecombineerde regressiemodel verhoogde de verklaarde variantie ten opzichte van een model waarin alleen USER werd gebruikt. Op basis van deze resultaten kunnen we concluderen dat de combinatie van IMU-gemeten houdingsstabiliteit en USER-gegevens de voorspelling van functioneel herstel bij ontslag potentieel kan verbeteren. De beoordeling van lichaamszwaai bleek echter te uitdagend voor niet-ambulante patiënten, wat de toepasbaarheid voor deze subgroep beperkt.

In **hoofdstuk 6** werd een IMU ingezet om fysieke activiteit, sedentair gedrag en hun veranderingen tijdens de geriatrische revalidatie te meten bij 53 patiënten die herstelden van een herseninfarct of hersenbloeding. Tijdens de revalidatie brachten patiënten het grootste deel van hun wakkere uren sedentair door. Ondanks verbeteringen in functionele prestaties was er slechts een minimale toename in fysieke activiteit en geen significante veranderingen in sedentair gedrag of de patronen van sedentair gedrag. Bovendien verschilde de mate van verandering in fysieke activiteit en sedentair gedrag aanzienlijk tussen individuele patiënten, waarbij de variabiliteit in fysieke activiteit groter was dan in sedentair gedrag.

Hoofdstuk 7 beschrijft de resultaten van een cross-sectionele cohortstudie die fysieke activiteit, sedentair gedrag en de patronen van sedentair gedrag kwantificeerde bij 43 patiënten die herstelden van een heupfractuur, drie maanden na geriatrische revalidatie. De resultaten toonden aan dat ouderen die herstelden van een heupfractuur zeer lage niveaus van fysieke activiteit vertoonden en lange periodes in sedentair gedrag doorbrachten. Op basis van bewegingspatronen, beoordeeld met een draagbare sensor, konden drie groepen worden onderscheiden, elk gekarakteriseerd door verschillende intensiteiten van fysieke activiteit en sedentair gedrag. Binnen deze groepen werd een duidelijke associatie gevonden tussen een lage intensiteit van fysieke activiteit in combinatie met lange sedentaire periodes en lagere scores voor mobiliteit, fysieke functie, heupfractuur, kwaliteit van leven en een grotere angst om te vallen.

Conclusie

Op basis van de bevindingen in dit proefschrift is onze belangrijkste conclusie dat eHealth potentie heeft om de revalidatie-uitkomsten voor ouderen die geriatrische revalidatie ontvangen te verbeteren. Blended en eenvoudige eHealth-interventies zijn hierbij het meest veelbelovend en haalbaar. Ondanks de potentie blijft de adoptie van eHealth in de geriatrische revalidatie nog steeds beperkt. Belangrijke obstakels moeten worden overwonnen, zoals het gebrek aan bruikbaarheidsuitkomsten, het ontbreken van een organisatie brede implementatiestrategie en de dringende behoefte van zorgprofessionals aan betrouwbare informatie over hoe eHealth effectief te identificeren, gebruiken en evalueren. Ons model, *Patiëntreis & domeinen van eHealth* (figuur 1), kan hierbij dienen als een gids voor zowel patiënten als zorgprofessionals om het gebruik van eHealth in de geriatrische revalidatie te begrijpen. Daarnaast hebben draagbare sensoren bewezen in staat te zijn om fysieke activiteit, sedentair gedrag en de patronen van sedentair gedrag bij ouderen te kwantificeren, zowel tijdens als na de geriatrische revalidatieperiode. Opmerkelijk is dat deze populatie zeer lage niveaus van fysieke activiteit vertoont en het merendeel van hun wakkere uren in sedentair gedrag doorbrengt. Tot slot toont het gebruik van draagbare sensoren potentie om de voorspelling van functioneel herstel bij ontslag te verbeteren.

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2023 Kraaijkamp JJM, Persoon A, Aurelian S, Bachmann S, Cameron ID, Choukou M-A, Dockery F, Eruslanova K, Gordon AL, Grund S, et al. eHealth in Geriatric Rehabilitation: An International Survey of the Experiences and Needs of Healthcare Professionals. Journal of Clinical Medicine. 2023; 12(13):4504. doi:10.3390/jcm12134504

2021 Kraaijkamp JJM, van Dam van Isselt EF, Persoon A, Versluis A, Chavannes NH, Achterberg WP. eHealth in Geriatric Rehabilitation: Systematic Review of Effectiveness, Feasibility, and Usability. J Med Internet Res 2021;23(8):e24015 doi: 10.2196/24015

Other publications

2020 Kraaijkamp JJM, van Dam van Isselt EF, Persoon, Chavannes NH, Achterberg WP. eHealth in de geriatrische revalidatie Lessen uit een systematic review over effectiviteit, haalbaarheid en bruikbaarheid Tijdschrift voor ouderengeneeskunde. Augustus 2020

2018 Kraaijkamp JJM , Peters J. Voorspellende factoren voor de ontslagbestemming bij geriatrische patiënten die na een CVA revalideren in het ZZG Herstelcentrum. Verpleegkunde. September 2018

Presentations at (inter)national conferences

2024 Changes in physical activity and sedentary behaviour following geriatric rehabilitation in older adults with stroke. UNC-ZH symposium 2024 (oral presentation)
Changes in physical activity and sedentary behaviour following geriatric rehabilitation in older adults with stroke. Congres geriatrische revalidatiezorg (oral presentation)
Changes in physical activity and sedentary behaviour following geriatric rehabilitation in older adults with stroke. Congres Making sense of sensor data (oral presentation)

eHealth in Geriatric Rehabilitation: an international consensus study. European Geriatric Medicine Society 2024 (oral presentation)
Changes in physical activity and sedentary behaviour following geriatric rehabilitation in older adults with stroke. Een zonnige toekomst voor de geriatrische revalidatie: Succesvolle toepassingen van het uitdagend revalidatieklimaat. (oral presentation)

2023 Using wearables in stroke rehabiliation. Hersenletselcongres (workshop)
internationale survey:eHealth in de geriatrische revalidatie. SANO wetenschapsdag (poster presentation)
Movement Patterns in Older Adults Recovering From Hip Fracture. Regionaal Refereeravond revalidatie LUMC (oral presentation)

2022 eHealth in Geriatric Rehabilitation: An International Survey of the Experiences and Needs of Healthcare Professionals. European Geriatric Medicine Society 2022 (oral presentation)
eHealth in Geriatric Rehabilitation: Systematic Review of Effectiveness, Feasibility, and Usability. SANO wetenschapsdag (online presentation)

Factsheets and infographics

2022 eHealth in Geriatric Rehabilitation: An International Survey of the Experiences and Needs of Healthcare Professionals. 2022; UNC-ZH_EAGER_Factsheet_International_survey_results.pdf

2021 eHealth in Geriatric Rehabilitation: national survey of Survey of the Experiences and Needs of Healthcare Professionals. Information for healthcare professionals 2021; UNC-ZH_EAGER_Infographic_Zorgprofessionals.pdf
eHealth in Geriatric Rehabilitation: national survey of Survey of the Experiences and Needs of Healthcare Professionals. Information for physio therapists 2021; UNC-ZH_EAGER_Infographic_Fysiotherapeuten.pdf

2020 eHealth in Geriatric Rehabilitation: national survey of Survey of the Experiences and Needs of Healthcare Professionals. A pilot study. 2020; UNC-ZH_EAGER_Infograhic_Pilot-studie.pdf

DANKWOORD

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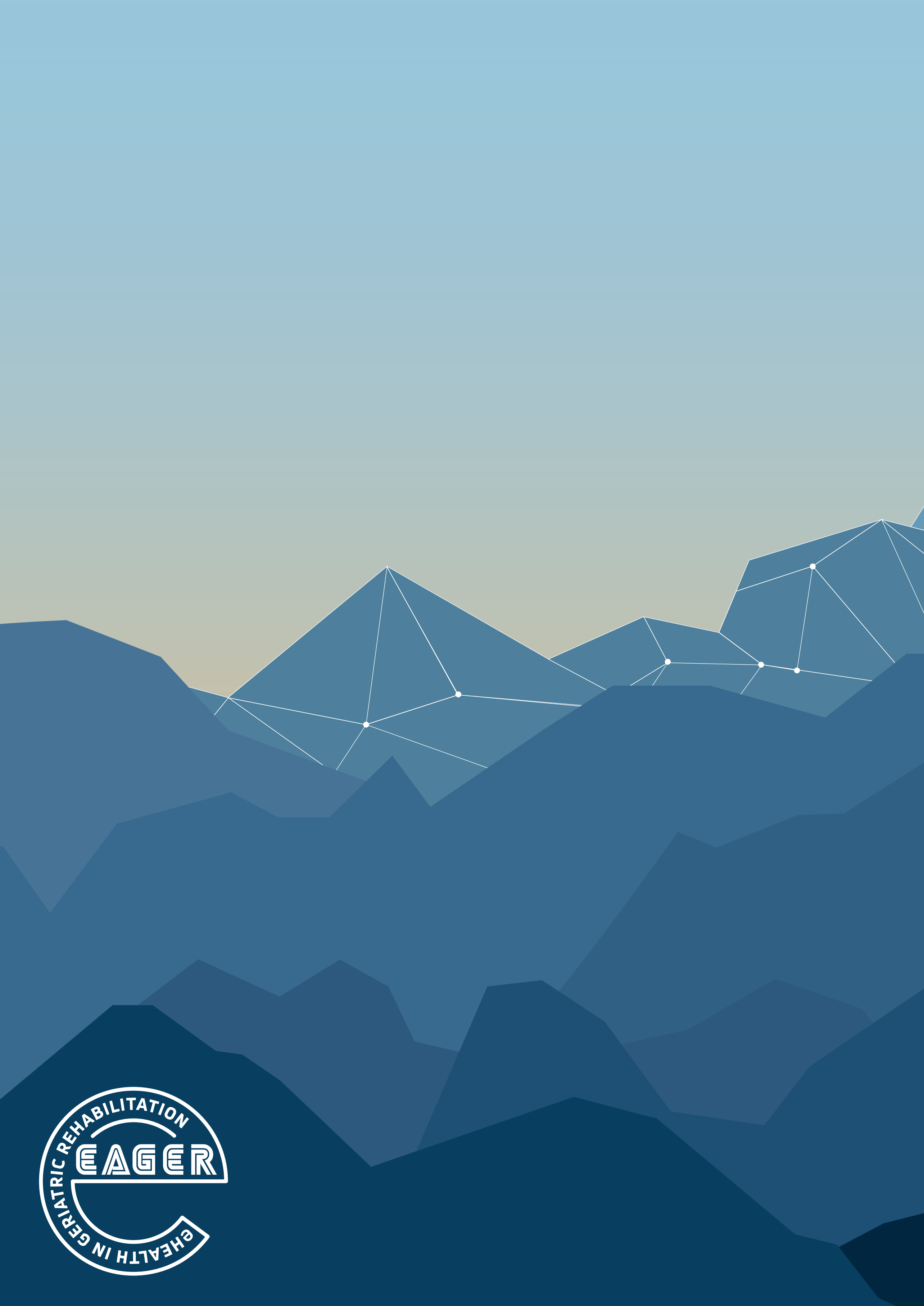
CURRICULUM VITAE

Jules Kraaijkamp was born on December 19, 1987, in Venray, the Netherlands. He completed his secondary education at Raayland College in Venray in 2000. Following this, he embarked on his professional journey in healthcare by starting as Healthcare Assistant at Gilde in Venray, where he graduated in 2004. He then pursued a degree in Nursing at ROC Eindhoven, successfully completing his studies in 2009. Building on this degree, he advanced his education further by undertaking a Bachelor's degree in Nursing at HAN University of Applied Sciences in Nijmegen, graduating in 2012.

In 2013, Jules Kraaijkamp began his career as a nurse at a geriatric rehabilitation center within ZZG Zorggroep in Nijmegen. The following year, he started a Master's degree in Advanced Nursing Practice at HAN University of Applied Sciences in Nijmegen, graduating cum laude with a Master of Science in 2016. As a Nurse Practitioner, he specialized in the care of older adults recovering from stroke in a geriatric rehabilitation setting. In 2017, he expanded his role as a Case Studies Instructor for the Master Advanced Nursing Practice at the HAN University of Applied Sciences.

In 2019, Jules Kraaijkamp began his PhD research at the Department of Public Health and Primary Care at Leiden University Medical Center. His research focused on the EAGER study (EHeAlth in GEriatric Rehabilitation), aimed at establishing a foundation for evidence- and practice-based eHealth interventions. During his PhD, he was also affiliated with the University Knowledge Network for Elderly Care Nijmegen (UKON) at Radboudumc. Additionally, Jules served as an instructor for the Master's program in Technical Medicine, specializing in Extramural Sensing and Virtual Stimulation (Leiden University and TU Delft). In September 2024, he transitioned from his role as a Nurse Practitioner to become a Senior Lecturer for the Master Advanced Nursing Practice at HAN University of Applied Sciences in Nijmegen.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