Connected Recovery in Motion

Sensors, Self-Management, and Sedentary Behaviour in Geriatric Rehabilitation

Suzanne Debeij

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COLOPHON

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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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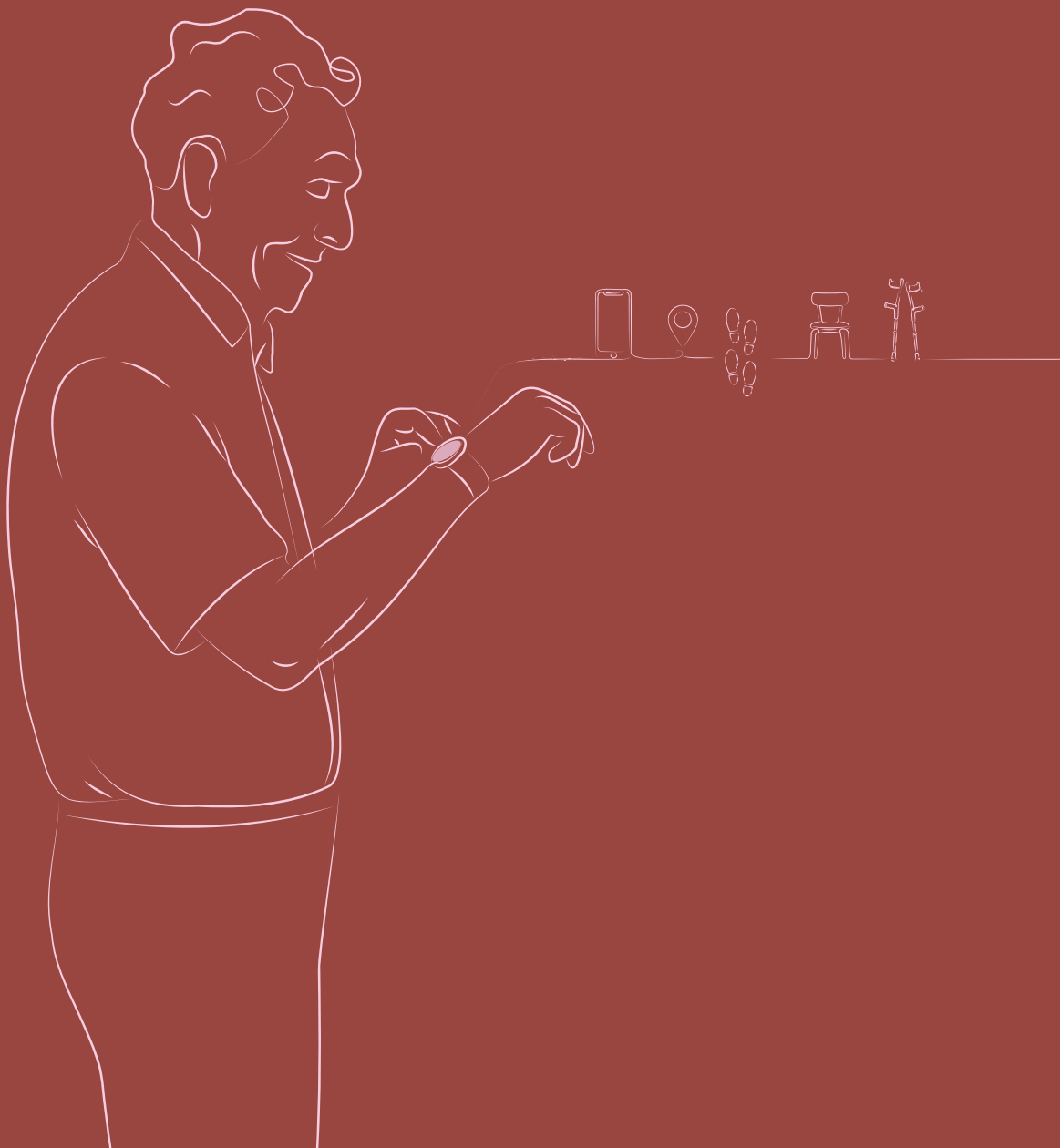

Chapter 1

General Introduction

GENERAL INTRODUCTION

The ageing population is one of the megatrends shaping societies worldwide[1]. In 1990, six percent of the global population was aged 65 years or older. By 2019, this proportion had increased to nine percent, and it is expected to reach sixteen percent by 2050. This demographic shift is even stronger in the Netherlands, where older adults already represented nineteen percent of the population in 2019 and are expected to represent twenty-four percent in 2050[2].

Although many older adults remain vital and independent, ageing is also associated with an increased prevalence of functional decline, multimorbidity and geriatric syndromes[3, 4]. These age-related declines can have synergistic interactions and increase the risk of an acute event and adverse outcomes[5]. When such an acute event happens, older adults require adequate support to restore their quality of life and, as far as possible, their independence. Geriatric rehabilitation plays a critical role in helping these older adults restore functional ability and improve functional capability[6].

Geriatric rehabilitation

Geriatric Rehabilitation is a multidimensional approach that includes both diagnostic and therapeutic interventions. Geriatric rehabilitation has been shown to improve functional outcomes, and reduce nursing home admissions, carer burden and mortality[6-8]. Its goal is to optimize functional capacity, promote activity, and preserve functional reserve and social participation in older adults with disabling impairments[9]. Additionally, geriatric rehabilitation promotes independence in everyday activities and enables participation in education, employment, recreation and meaningful roles such as taking care of family[8].

Geriatric rehabilitation uses generic and comprehensive assessment methods to drive individualized treatment plans. Because some groups require specific areas of concern, treatment programs for stroke, fractures, oncological diseases, and chronic organ failure like chronic obstructive pulmonary disease (COPD) can be distinguished. The rehabilitation can be delivered in an inpatient setting, at home, or through a combination of both, where home-based rehabilitation often serves as a transitional phase before discharge[6, 10]. The content of the rehabilitation is personalized to the individual's needs and prepares them for daily life after discharge, including coping with adaptations that might be needed to deal with chronic impairments. Therefore, one of the

key objectives in geriatric rehabilitation is to optimize self-management by improving patients' ability to manage living with, and increasing their resilience to, condition-related changes in daily life.

Self-management

Self-management refers to the behaviours that a person uses to manage the medical, social, and emotional consequences of a condition by making informed decisions and adapting to the changing circumstances caused by the condition[11]. Managing ones' self is a process that involves the handling of everyday tasks, such as dealing with emotions, maintaining meaningful behaviours, and adhering to specific dietary or exercise routines[11-13]. To handle these tasks, skills including problem solving, decision making and action planning are required[11].

Optimizing self-management can improve health outcomes in older adults with chronic diseases[14-16]. Strategies such as enhancing knowledge, setting goals and self-monitoring of behaviour can be used to optimize self-management[17]. Within geriatric rehabilitation, optimizing handling of self-management tasks includes encouraging patients to engage in physical activity to improve functional performance. However, despite this focus, patients in geriatric rehabilitation spend most of their day sedentary[18, 19]. This is concerning, as prolonged sedentary behaviour is associated with an increased risk of various non-communicable diseases and all-cause mortality[20, 21].

Sedentary behaviour

Sedentary behaviour consists of any waking behaviour resulting in an energy expenditure of ≤ 1.5 Metabolic Equivalent of Task while in a sitting, reclining, or lying posture[22]. Importantly, the risks associated with prolonged sedentary time occur independently of a person's physical activity level. In other words, even individuals who meet the WHO activity guidelines may still have elevated health risks if they spend substantial time sedentary.

Not only the total sedentary time, but also the pattern in which it is accumulated contributes to these risks[23]. To clarify, this indicates that a person that sits multiple consecutive hours without interruptions has a higher risk of adverse outcomes than someone who spends the same amount of time sedentary but frequently interrupts the sitting. However, the precise threshold at which sedentary time becomes harmful, and what reduction is clinically relevant, remains unclear. Consequently, the WHO guideline simply advises to 'limit the

amount of time spent being sedentary'[24]. This recommendation is difficult to translate into specific, measurable goals. Dogra et al. (2022)[21] therefore proposed a stepwise approach to initiate changes in activity behaviour (figure 1). This approach, particularly relevant to those with chronic diseases or physical impairments, encourages to start behaviour change by reducing sedentary time. They propose to do so by increasing sit-to-stand transitions to interrupt sitting and subsequently reduce the total sedentary time. Following success in step one, additional steps towards an active lifestyle may follow.

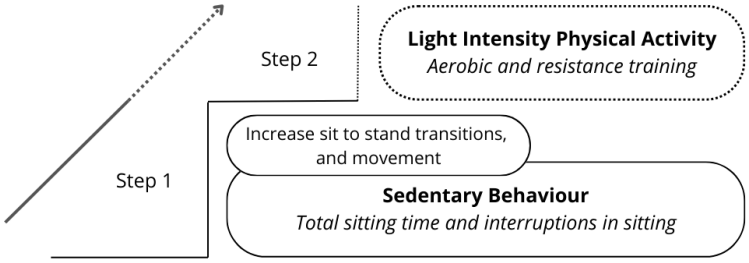

Figure 1. Visualisation of the first two of four steps of the stepwise approach to reducing sedentary behaviour, adapted from Dogra et al.[21]

This stepwise approach may be especially needed in geriatric rehabilitation, where patients spend over nine hours a day sedentary[18, 19]. The high level of sedentary time persists throughout the rehabilitation and after discharge[25, 26]. These older adults with higher age, reduced functional capacity and chronic conditions tend to spend more time sedentary than healthier, younger older adults[27]. Despite these risks, there is limited knowledge on how to best support older adults in geriatric rehabilitation in reducing sedentary behaviour. Combining the first step of the stepwise approach with the optimization of self-management skills may offer a feasible starting point for health behaviour change. Strategies such as goal setting, receiving feedback and self-monitoring of behaviour could be applied to initiate that change. One of the methods to deliver and support these strategies is through eHealth technologies, including websites, applications, and wearable sensors such as smartwatches and smartphones. eHealth can offer advantages compared with traditional approaches, such as continuous access, increased communication and more personalised care.

To illustrate how eHealth can play a potential role in filling the needs in geriatric rehabilitation in support of self-management and sedentary behaviour, the following case is presented.

Case of Ms. van Stavenberg

Ms. van Stavenberg is an 83-year-old woman who recently experienced a stroke. Before the stroke, she was physically healthy and functionally independent. She walked without aids, managed all daily activities, like doing her own groceries, and attended a weekly sports club. She also had a strong intrinsic motivation to stay active and engage in modern technology. She sent photos to her (grand)children via WhatsApp, sent them direct messages on social media, made birthday and Christmas cards online, had recently learned to use online banking, and monitored her daily step goals using her smartphone and smartwatch.

Following the stroke, she was admitted to geriatric rehabilitation. At the start of her rehabilitation, her mobility was limited, and she required support for daily activities such as dressing and bathing. As a result, she spent long periods seated or lying down between therapy sessions. Although she had learned she would not be able to fully recover to her pre-stroke level, she remained highly motivated to regain her independence and return home. She was eager to resume her hobbies and re-establish her daily routines. She wanted to make the most of her rehabilitation and wished to engage in more therapy but knew that the rehabilitation team's schedule limited the amount of supervised treatment that was available.

Given her familiarity with technology, she wondered whether her smartphone and smartwatch could enhance her rehabilitation by regularly encouraging her to do activities between therapy sessions and supporting her goals.

eHealth

eHealth can be defined as "the use of digital information and communication to support and/or improve health and health care"[28]. eHealth Interventions may include a wide range of tools, from video communication and wearable sensors to more complex treatment applications involving virtual reality. These eHealth interventions have been successfully implemented in healthcare and have shown positive effects on various health outcomes[29]. Among these outcomes are self-management and activity-related behaviours, including sedentary behaviour.

In geriatric rehabilitation, eHealth may improve rehabilitation outcomes, particularly when delivered as blended care, where the use of eHealth is integrated into care pathways and combined with face-to-face treatment[30]. Blended approaches are especially promising when they use simple eHealth interventions such as video communication or wearable sensors. Despite this potential, only a small proportion (20%) of healthcare professionals in geriatric rehabilitation integrate eHealth into daily practice[31]. One explanation may be that eHealth interventions are not developed in co-creation with stakeholders, and therefore do not sufficiently align with the skills, needs and preferences of both older adults and healthcare professionals. Another explanation could be that, compared to conventional methods, eHealth may present several challenges, including limited experience with eHealth, low digital literacy, data fragmentation, misinterpretation of data and a lack of validated interventions.

Personalized support and co-creation with multiple stakeholders during the development, implementation, and evaluation of eHealth interventions can help overcome some barriers and improve intervention fit within the complex rehabilitation context[32]. Furthermore, assessing stakeholders' perspectives on usability elements (such as ease of use, added value and user satisfaction) and on feasibility aspects (including practical integration into existing workflows, logistics, and adherence) is crucial for successful implementation of eHealth interventions in geriatric rehabilitation[33]. However, current knowledge regarding the use, usability, and feasibility of eHealth interventions within the rehabilitation context remains limited[30].

Wearable sensors

Among the various forms of eHealth, wearable sensor monitoring technology has the potential to improve the quality of rehabilitation[30, 34]. Sensors are generally easy to use, lightweight, and often capable of providing continuous feedback on activity behaviour. This technology can support patients and healthcare professionals in jointly setting medication or activity goals, after which patients can monitor their own progress. Subsequently, professionals can provide feedback based on the monitored data and, together with the patient, change the goals as needed[34]. Therefore, the use of wearable sensors in geriatric rehabilitation holds considerable promise for supporting self-management and reducing sedentary behaviour.

Despite the potential of wearable sensors and the seemingly easy use, evidence on the use of sensor monitoring technology in geriatric rehabilitation remains

limited. There is a lack of knowledge about stakeholders' perspectives on barriers and facilitators, as well as on objectively measured sedentary outcomes. As a result, the application of sensor monitoring technology in geriatric rehabilitation to support self-management and reduce sedentary behaviour is not reaching its full potential.

Aim of this thesis

The current thesis describes the findings of the EAGER-2-SEE study (EheAlth in GEriatric Rehabilitation to improve SElf-managEment). The overall aim of this thesis is to provide evidence on how sensor monitoring technology can be used to support the self-management of older adults during geriatric rehabilitation. More specifically, this thesis focuses on the use of sensor monitoring technology in relation to reducing sedentary behaviour. Accordingly, the central research question of this thesis is:

How can sensor monitoring technology be applied in geriatric rehabilitation to improve self-management and reduce sedentary behaviour?

To answer this research question, the following sub-questions are addressed. All studies were carried out in or focused on the geriatric rehabilitation setting.

- What are the potential use and value of a sensor monitoring bracelet for patients with COPD at high risk for an exacerbation?
- What are the usability and feasibility of a sensor monitoring system that is iteratively adapted to geriatric rehabilitation?
- What is the effectiveness of interventions using feedback based on objective measurements to decrease sedentary behaviour?
- What are the usability and feasibility of a sensor monitoring system that provides feedback on sedentary behaviour?
- What is the influence of Hospital-At-Home for older individuals with transient ischemic attack (TIA) or minor stroke on sedentary time during the first week after stroke, compared to those receiving usual care?

Outline of this thesis

This thesis is structured as follows. The first chapters focus on the application of sensor monitoring technology to support self-management in older adults receiving geriatric rehabilitation for COPD. **Chapter 2** describes a qualitative study exploring the perspectives of healthcare professionals and patients on the

potential use and value of a sensor monitoring bracelet for patients with COPD at high risk for exacerbation. This chapter also addresses anticipated facilitators and barriers related to the bracelet's use and implementation. **Chapter 3** examines the usability and feasibility of a sensor-based monitoring system during inpatient rehabilitation for patients with COPD. In this participatory mixed-method study, patients and their healthcare professionals used a digital monitoring system during rehabilitation, and the system was adapted iteratively to improve the support of patients' self-management.

In the subsequent chapters, the focus shifts to the role of sensor monitoring technology in the reduction and objective measurement of sedentary behaviour as a component of self-management during geriatric rehabilitation. **Chapter 4** presents a systematic review evaluating the effectiveness of interventions that incorporate feedback from objective measurements to reduce sedentary behaviour. **Chapter 5** examines the perspectives of patients and healthcare professionals on the usability and feasibility of a sensor-based monitoring system that provides feedback on sedentary behaviour. In this mixed-method study, patients used the sensor during both the inpatient and the home-based part of their rehabilitation. **Chapter 6** explores sedentary time in the first week after stroke among older adults with transient ischemic attack (TIA) or minor stroke. In this exploratory sub-study within a randomized controlled trial, sedentary behaviour in patients receiving the Hospital-at-Home programme supported by a digital platform is compared with that of patients receiving usual care. Finally, **Chapter 7** discusses the main findings of this thesis, reflects on methodological considerations, and presents implications and recommendations for clinical practice and policy, education, and research.

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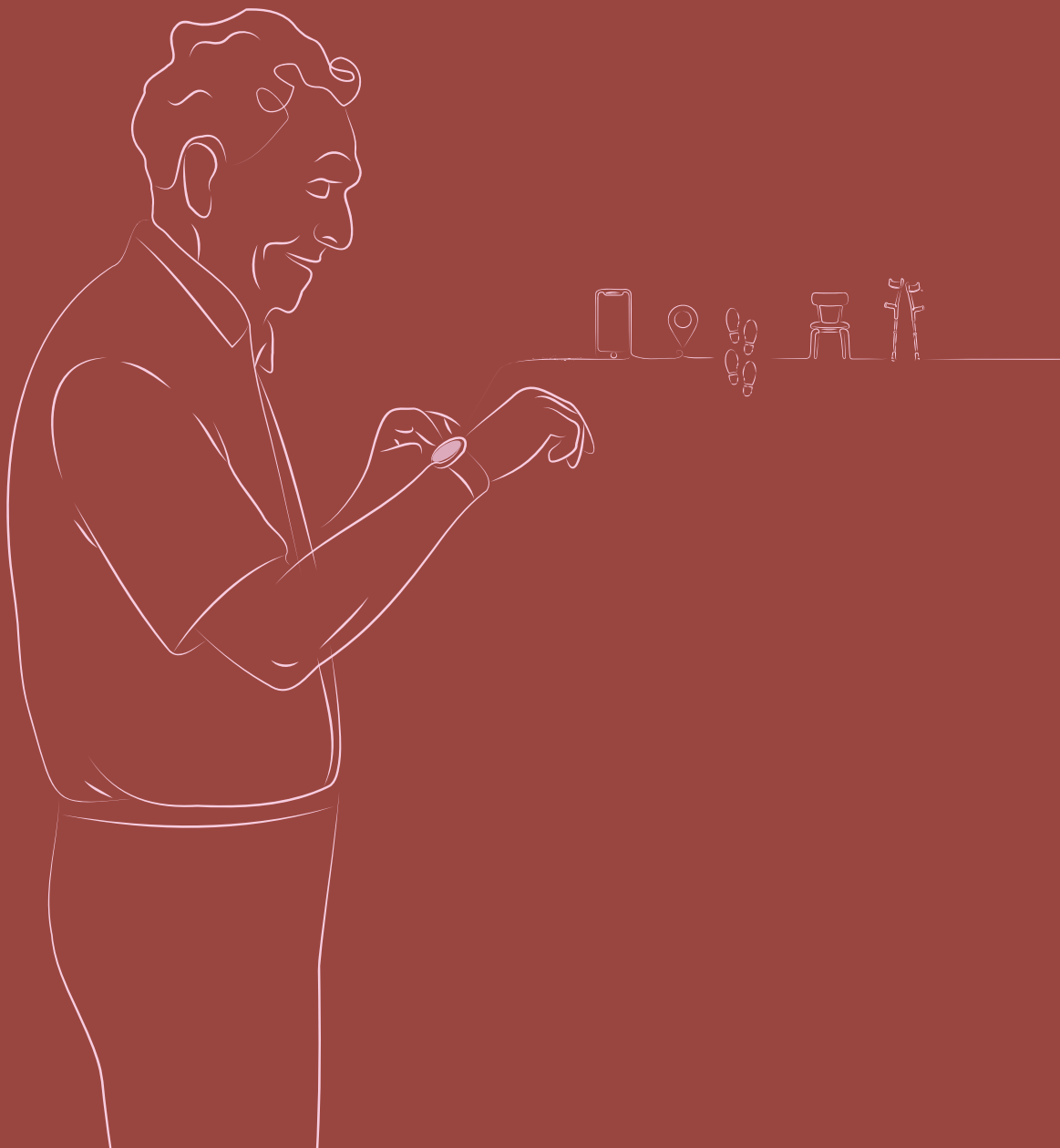

Chapter 2

The potential use and value of a wearable monitoring bracelet for patients with chronic obstructive pulmonary disease: qualitative study investigating the patient and health care professional perspectives

Suzanne Debeij
Jiska Aardoom
Miriam Haaksma
Wieteke Stoop
Eléonore van Dam van Isselt
Marise Kasteleyn

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ABSTRACT

Background: The occurrence of exacerbations has major effects on the health of people with chronic obstructive pulmonary disease (COPD). Monitoring devices that measure (vital) parameters hold promise for timely identification and treatment of exacerbations. Stakeholders' perspectives on the use of monitoring devices are of importance for the successful development and implementation of a device.

Objective: This study aimed to explore the potential use and value of a wearable monitoring bracelet (MB) for patients with COPD at high risk for exacerbation. The perspectives of healthcare professionals as well as patients were examined, both immediately after hospitalization and over a longer period. Furthermore, potential facilitators and barriers to the use and implementation of an MB were explored.

Methods: Data for this qualitative study were collected from January to April 2023. A total of 11 participants (e.g., n=6 healthcare professionals (HCPs), 2 patients and 3 additional patients) participated. In total, 2 semistructured focus groups were conducted via video calls; 1 with HCPs of various professional backgrounds and 1 with patients. In addition, 3 semistructured individual interviews were held with patients. The interviews and focus groups addressed attitudes, wishes, needs, as well as factors that could either support or impede the potential MB use. Data from interviews and focus groups were coded and analyzed according to the principles of the framework method.

Results: HCPs and patients both predominantly emphasized the importance of an MB in terms of promptly identifying exacerbations by detecting deviations from normal (vital) parameters, and subsequently alerting users. According to HCPs, this is how an MB should support the self-management of patients. Most participants did not anticipate major differences in value and use of an MB between the short-term and the long-term periods after hospitalization. Facilitators of the potential use and implementation of an MB that participants highlighted were ease of use and some form of support for patients in using an MB and interpreting the data. HCPs as well as patients expressed concerns about potential costs as a barrier to use and implementation. Another barrier that HCPs mentioned, was the prerequisite of digital literacy for patients to be able to interpret and react to the data from an MB.

Conclusions: HCPs and patients both recognize that an MB could be beneficial and valuable to patients with COPD at high risk for an exacerbation, in the short as well as the long-term. In particular, they perceived value in supporting self-management of patients with COPD. Stakeholders would be able to utilize the obtained insights in support of the effective implementation of MBs in COPD patient care, which can potentially improve health care and the overall well-being of patients with COPD.

Keywords: *eHealth, Chronic Obstructive Pulmonary Disease (COPD), wearable, exacerbation, self-management, monitoring bracelet, remote monitoring, mobile phone*

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a chronic progressive inflammatory lung disease characterized by persistent respiratory symptoms and airflow limitation. It affects millions of people worldwide and places a substantial economic and health burden on societies and patients[1-3]. A major challenge associated with COPD is the occurrence and recurrence of exacerbations, which involve acute and sustained worsening of symptoms[4]. Exacerbations not only accelerate disease progression, but also lead to reduced health-related quality of life, increased health care use, poor health status, and even mortality[5-7]. It is estimated that one-third of patients with COPD who have been hospitalized due to an acute exacerbation are readmitted within 1 year[8, 9]. Consequently, preventing exacerbations is an important part of COPD care. Essential to preventing exacerbations and improving health outcomes is optimizing self-management of patients with COPD[10-12]. Self-management is an iterative process during which patients use strategies to actively cope with their chronic disease within the context of their daily life[13]. Goals to optimize self-management can, for example, be directed at improving exacerbation and energy management.

In recent years, advances in telemedicine and remote patient monitoring have shown great potential to support self-management and enable timely identification and treatment of COPD exacerbations[14-20]. Wearables such as monitoring bracelets can, for example, measure various (vital) parameters to detect early COPD symptom deterioration and so allow for more timely interventions . This can reduce severity of exacerbations, and therefore prevent hospital admissions. Besides early detection of deterioration, wearables can provide both patients and professionals with insight into patients' recovery patterns. This may increase patients' awareness about their health status during stable periods, before an exacerbation, and throughout the recovery period following an exacerbation. This, in turn, empowers them to engage in self-management.

While the use of a monitoring bracelet (MB) in COPD patient care seems promising, its integration into health care is a complex and challenging process. The monitoring device should fit the physical, social, and cultural environment[21]. Therefore, we focused on the Dutch healthcare setting to ensure the fit of the MB in that context. To realize this, stakeholders' perspectives on the use of monitoring devices are of crucial importance for the successful development

and implementation of such devices. Poor digital health literacy of users, security and a design that do not fit users' needs are some of the barriers to effective implementation[22, 23]. However, relatively little is known about the perspectives of health care professionals on the use of wearables to support COPD management[24]. Yet their insights on the use and value of wearables are of crucial importance to enable successful integration into clinical practice. Regarding the patient perspective, a recent systematic review did not find a clear role of wearables in improving health outcomes in chronic disease. That is, both positive and neutral outcomes were found when investigating the impact of wearables on health care outcomes[24]. More research is needed to examine the ways in which different functionalities of wearables can aid in the management of specific types of chronic diseases. This study, therefore, aimed to explore the potential use and value of an MB for patients with COPD in the Dutch healthcare setting at high risk for an exacerbation. Perspectives of health care professionals (HCPs) and patients regarding the use and value of an MB in the period immediately following hospitalization and later were examined. In addition, potential facilitators and barriers to the use and implementation of a wearable were explored.

METHODS

Study design

This qualitative study comprised 2 semi-structured focus groups, 1 with health care professionals (HCPs)and the other consisting of patients with COPD. Because of technical issues during the focus groups for patients, 3 individual interviews with patients were conducted to supplement the data. The period of data collection ran from January 31 to April 21, 2023. The reporting of this study follows the guidelines of the Consolidate Criteria for Reporting Qualitative Studies (COREQ; Appendix 1)[25].

Ethical Considerations

The study was declared not to fall under the scope of the Dutch Medical Research Involving Human Subjects Act (WMO) by a non-WMO review board of the Leiden University Medical Center and was granted a certificate of no objection (reference number 22-3020). The study was carried out in accordance with the General Data Protection Regulation (GDPR). All participants provided informed consent before their participation. Participants had the ability to opt out. Patients received a €25 (US $27.74) gift voucher for their participation.

HCPs received a €100 (US $110.95) gift voucher. All participant data was pseudonymized to ensure confidentiality.

Participants

Both patients with COPD and HCPs were recruited from the Revant rehabilitation center and the Franciscus Gasthuis & Vlietland hospital in the Netherlands. To be eligible to participate, patients needed to (1) be aged 18 years or older, (2) have a diagnosis of COPD, (3) have been admitted to the hospital for an acute exacerbation of COPD in the past 2 years, and (4) be able to understand, read and speak the Dutch language. The eligibility criteria for HCPs were that they must have been treating patients with COPD in one of the participating institutions. HCPs could have occupations such as pulmonary nurse, physical therapist, or pulmonologist.

Study procedures

Potential HCPs were purposively sampled, approached, and informed of the study by representatives from the participating institutions with an information letter. Potential patients with COPD were approached and informed of the study by their HCP. Participants were informed that Corsano Health (Corsano Health B.V.) develops medical bracelets for remote patient monitoring. Some examples of the 20 parameters that the bracelet can measure were provided. However, participants did not have the opportunity to see or try the bracelet. Before the study, participants received an invitation to join an online focus group via Microsoft Teams. If patients with COPD were not able to participate in the focus group, they were scheduled for an individual interview by phone.

Focus groups and interviews

A total of 4 female researchers participated (authors JA, SD, and MK, and researcher EO) in the data collection. Participants had not met the researchers before and did not have knowledge of the interviewer. All researchers had experience in qualitative research and made notes. No other people were present during focus groups and interviews. The focus groups and individual interviews both followed a predetermined semi-structured interview guide (Appendix 2). At the start of the interview, descriptive characteristics were collected. The main part of the interviews and focus groups contained questions regarding the participants' attitudes, wishes, and needs for an MB, as well as potential facilitators and barriers related to the use and implementation of an MB. The questions covered the recovery period directly after an exacerbation as well as long-term use in the prevention of exacerbations. To gather

participants' perspectives on all these topics, they were presented with an example of an existing MB (i.e., the Corsano Cardiowatch [Corsano Health B.V.]) and its corresponding functionalities were explained. The Corsano Cardiowatch is a medically certified health MB that is able to continuously measure health-related parameters such as heart rate, heart rate variability, breathing rates, skin temperature, physical activity (e.g., steps and cadence), and sleep. These parameters are measured by an accelerometer and photoplethysmogram sensor. The bracelet offers flexible data collection intervals, and data are subsequently privately stored in a health cloud. These data can be safely and continuously transferred to the patient's healthcare professional via a digital platform. Hence, the watch is an unobtrusive tool to continuously monitor a patient's (vital) parameters. An example of a question asked is "What are your general needs and ideas about the monitoring bracelet?"

Data analyses

Descriptive analyses were conducted to summarize the sociodemographic characteristics of patients and HCPs. The interview was audio recorded and the recording was stored in a restricted secure data folder of the Leiden University Medical C enter. Interviews were transcribed and not returned to participants. Due to technical issues, one recording failed and so notes made during this interview were used in the data analysis. The transcribed interviews were coded and analysed according to the principles of the framework method[26]. Data were coded using Atlas.ti software (version 22, ATLAS.ti Scientific Software Development GmBH). Coding was performed by 2 researchers (SD and JA or MK). The second coder repeated the process on samples from the interviews to verify codes. A code tree was created, and codes were discussed until consensus was reached. The analysis was used to categorize recurrent and common themes and to identify key elements in the interviews. Participants did not provide feedback on the findings.

RESULTS

Overview

A total of 5 patients with COPD and 6 HCPs participated in this study. The HCPs worked in a hospital or in a rehabilitation centre as a pulmonologist (n=2), nurse (n=2), nurse practitioner (n=1) or physical therapist (n=1). Patients were aged between 60 and 80 years and had COPD GOLD (Global Initiative for Chronic Obstructive Lung Disease) stage 3 or 4. The interviews took approximately

30 minutes, the focus groups took 1 hour. Results are presented as (1) MB in support of self-management, (2) expected use of an MB during the course of illness, and (3) facilitators and barriers. The exact number of individuals that were invited for participation and declined is unknown.

MB in support of self-management

The first aspect that most patients described as valuable in an MB is its ability to help with the (very) early recognition of an exacerbation. Some participants specifically stated that it should register and interpret trends in (vital) parameters, and subsequently notify them in case of deviations from normal values.

…I expect the bracelet to warn me that there is something wrong with me before I notice it myself. [male, patient]

Valuable (vital) parameters that an MB should be able to measure, according to participants, are oxygen saturation, respiration (frequency), heart rate and physical activity, because these measures are informative about a person's health status. For physical activity, different variables were mentioned: step count, type of performed activities (such as standing or walking)and pace of movement. One HCP felt that step count is not an accurate parameter for early detection of exacerbations and emphasized the greater importance of vital parameters. Also mentioned by 1 HCP was the importance of additional information about a patient's perspective by offering the option of self-monitoring in an MB.

Another potential benefit frequently mentioned by both patients and HCPs was receiving alerts when data deviate from normal. Both groups acknowledged the importance of HCPs having access to their patients' monitoring data. However, there was no consensus on who should receive these alerts first. Some patients thought that the HCP should be alerted first and subsequently reach out to the patients, while other participants thought it was the patients' responsibility to reach out if something is wrong.

…When the time comes, you can call for help yourself. The watch doesn't have to do that, I can do it myself. The most important thing is that the watch lets me know me when something is wrong. [female, patient]

Most HCPs further mentioned that an MB should support patients in having ownership over their health. An MB can foster this ownership and give patients more autonomy by providing body awareness, finding rest, and providing awareness of and insight into normal values and trends. The HCPs further reported possible benefits for patients in terms of being able to ask for more specific help with their COPD when parameters deviate from normal, building confidence, reducing anxiety, feeling heard, and supporting the transition from the rehabilitation centre to their home. HCPs could for example discuss unusual data with patients and explore the reasons behind such deviations.

…I can imagine people will be motivated as they gain insight into their movement patterns and whether these stay within the set norms. That they become more confident and are able to ask for more specific help when they see deviations. [HCP]

Benefits and drawbacks of a monitoring bracelet

Benefits mentioned by patients were being able to act quickly, a sense of reassurance, heightened body awareness, improved insight into the disease and normal values and patterns, and finally, improved insight for informal caregivers into how the patient is doing. Possible drawbacks were also mentioned. Most HCPs felt that some patients might just focus on the data and not think critically, become obsessed with the data, or feel that their privacy was being invaded. They also described that the MB system should be integrated with the electronic patient dossier, because using multiple systems at the same time is laborious. Some patients also described the potential drawback of becoming obsessed with data, invasion of their privacy, and reluctance due to having to use yet another application. Several patients did not see any drawbacks in using an MB.

The expected use of monitoring bracelet during the course of illness

Most participants did not anticipate any potential difference between the short-term and the long-term use of an MB. Several participants said that an MB should be worn through all phases, that is, periods of well-being, exacerbation, and recovery, to obtain a comprehensive view of a patient's condition. It is important to remember that during recovery, parameters may still deviate from normal. One thing highlighted by HCPs that might be of added value in the long-term is a parameter to measure physical activity. HCPs did not consider step count to be suitable for detecting exacerbations in the short-term, but a decrease in the trend of steps taken could be a sign of deteriorating

health in the long-term. Patients did not differentiate between the importance of parameters in the long-term or the short-term.

HCPs further stated that patients could try the MB in the health care setting, to see if suits their abilities and needs. An MB could support the transition from a care setting to the home setting, by giving insight into changes in parameters.

…It might help us to better guide patients' transition from 10 weeks of comprehensive care to a "go do it yourself at home" approach. What difficulties do patients encounter? We often hear back: "it just didn't work out" or "I failed again" and then [with an MB] we can point out more specifically "I notice that…" [HCP]

Facilitators and barriers

A major facilitator for the use of an MB is providing support to patients on how to use the device. Some HCPs thought that patients will not be able to use an MB correctly without such support.

… I think this bracelet would be useless without instruction. Then [with instructions] *you will know if you're going into the right direction or maybe in a wrong direction.* [HCP]

The support could be in the form of a manual, video instructions, or even a whole support system with coaching from HCPs or support groups with other patients. This system could include coaching appointments with HCPs for regular feedback on parameters. Patients elaborated on the crucial role of support with statements about a decrease in motivation if they did not know how to use an MB. One patient mentioned that it would be useful if informal caregivers could also receive information about an MB.

HCPs also indicated that it was their responsibility to assess whether an MB could be of value to a person, and to provide guidance and coaching accordingly. Several HCPs said that patients in rehabilitation could learn how to use, practice, and interpret the system. Patients need to gain experience with an MB to know what values are normal within their own physique.

…I think it is our role to coach the patient. So giving good instructions, adequate cut-off scores, like this is when you need to get in touch and if you're within this range you are okay. [HCP]

In addition, an MB should be easy to use, should not malfunction, should provide signals that are tailored to a patient, and it should have an attractive design. Patients also described that it should have additional features compared to a regular smartwatch. Instructions on how to use and interpret the obtained data are an important precondition for MB use. Another important precondition for the use of an MB is ensuring the accuracy of the data and the reliable detection of abnormal values and trends. Additional preconditions mentioned by participants included standard procedures and protocols, an adequate battery life of the MB, ensuring privacy, affordable cost, and the bracelet being waterproof.

Despite a generally positive attitude, HCPs also see some barriers to the use of an MB in health care. For example, they mentioned the time required to monitor the data, which could lead to an increased demand for staff and therefore increased costs. They further mentioned that patients with COPD are often older and of lower socioeconomic status, which are risk factors for lower digital literacy. Patients described some of the same barriers, such as the potential costs, while also identifying some barriers on a more practical level, such as having to wear the device all the time. Furthermore, 1 patient mentioned she was afraid she would be overlooked if an MB malfunctioned.

… *They* [doctors] *are all so incredibly busy. I'm afraid I will be overlooked if I wear the watch, and something is wrong with the watch. We're already being overlooked now.* [female, patient]

DISCUSSION

Principal Findings

The results of this study show that Dutch patients and Dutch HCPs both have an overall positive and comparable view of the use and value of an MB in the care of patients with COPD. The most frequently mentioned value of an MB for patients with COPD, according to both HCPs and patients, is its support in self-management of COPD. In addition, HCPs indicated that an MB should support patients' ownership of their health. Furthermore, the support that patients would need to use an MB as well as the support that an MB could provide, were discussed. The potential benefits most frequently highlighted by HCPs and patients related to early detection and alerting in case of an exacerbation. There was no consensus on whether the alerts should be received by the HCP

or patient first. Participants did not anticipate major differences regarding the expected use of an MB during the course of illness. The most frequently mentioned facilitators for using an MB were adequate support (e.g., from HCP or peers) and instructions on how to use it correctly, ease of use, and an appealing design. Potential barriers were the need for time and staff to guide patients, costs (e.g., for purchase or guidance), and having to use multiple apps at the same time.

The need for support described by both HCPs and patients in this study in using and interpreting data from an MB is in line with the literature focused on patients. Target groups that have more problems with understanding and accessing eHealth in particular, are known to need more support in using it[27]. Previous literature shows that a platform supporting self-management of people with COPD was used more when participants received more personal support in how to use it[28]. HCPs in this study highlighted the importance of a comprehensive support system. This is in contrast with earlier literature where HCPs primarily emphasized the necessity of technological support alone[29]. Although a patient's motivation influences the use of eHealth, support increases the effectiveness of and adherence to eHealth interventions[30]. Support from others should be managed carefully, as factors such as the bond between patient and the person giving support and perceived legitimacy of the person giving support can influence the use of an eHealth intervention[27, 30].

Participants also described the support that an MB could provide at various timepoints in COPD, including stable phases and during recovery from an exacerbation. Support during these phases can be provided in various domains, which Gardener et al[31] grouped into four overarching categories: physical, psychological, social, and spiritual. Participants described support in the physical domain in terms of self-management. This form of support fits into the ‘managing symptoms and medications’ domain of support for managing life with COPD[29, 31]. The support that an MB can provide in managing one’s COPD, was also highlighted by participants in the study of Wu et al[32], who conducted a qualitative study on the needs of patients with COPD in applications that support their self-management. Other studies that implemented eHealth interventions and tools to support self-management of long-term conditions suggest that eHealth is safe and best used alongside usual care[33]. eHealth is most promising in blended care settings[28, 34]. As factors such as personality, lifestyle, progression of a chronic disease and environmental characteristics

influence self-management, they should be taken into consideration when developing eHealth to support self-management.

In addition, the ability to accurately detect early signs of an exacerbation by measuring deviations in (vital) parameters was highlighted as the most important characteristic an MB should have both shortly after an exacerbation as over a longer period. This is not surprising, as exacerbations have a detrimental effect on health and having an exacerbation is a major risk factor for another exacerbation[35]. Other predictors of exacerbations include comorbidities, disease severity, symptom burden and environmental factors[36, 37]. Predictors such as these cannot be measured by an MB. Nevertheless, other predictors of an exacerbation, such as decreased physical activity, pulse rate, oxygen saturation and respiratory rate, can be measured by an MB[36-39]. If an exacerbation is recognized and treated in time, the length and severity of the exacerbation can be reduced, which can support patients' short and long-term recovery[40].

An MB should be easy to use, according to the participants. This is in line with recent literature which suggests that simple eHealth interventions are more likely to be feasible and effective[34]. The desire of the elderly target group for an uncomplicated and familiar design of eHealth has been described earlier[41]. Therefore, an MB should be adapted to the skills, wishes, and needs of the target population[42]. The target population for an MB in COPD management does not only consists of patients, but also of HCPs. However, there is a lack of understanding regarding the perspective of the HCPs on the use of MBs in COPD care[24]. This study suggests that Dutch HCPs hold a positive view that complements the patient perspective. The inclusion of this additional perspective is of upmost importance, since cocreation with the target population can provide insight into the skills, wishes, and needs and thus facilitate an MBs use[41]. In addition, known barriers for target groups should be considered, such as cognitive barriers, physical disabilities, and lack of motivation[23, 41]. To ensure an optimal fit for the target population in a national context, not only the patient but also other stakeholders should be involved in the development process[44, 45].

As such, the use of non-obtrusive wearable devices appears to be beneficial and well accepted by patients and HCPs to be integrated into existing care, with little difference between long-term and short-term care. An MB could be combined with other eHealth solutions, such as smartphone apps and air

quality monitoring devices to increase the impact. To effectively implement an MB supporting the management of COPD, HCPs, patients, developers, and other stakeholders in the Dutch context should be informed and involved in the process. In both long-term and short-term care, an MB could help improve overall well-being, health outcomes and quality of life of patients with COPD.

Limitations

Participants indicated they were not familiar with the possibilities of an MB, which suggests that they may not be aware of all the facilitators and barriers relating to the use and implementation of an MB. For example, because they were not able to see or try the MB, they could not experience the unobtrusive, small, lightweight design and long battery life. Another limitation of this study is the small sample size. As a result, we are not sure if data saturation is sufficient to provide a representative perspective of the population. Nonetheless, given the explorative nature of this study, the sample size was sufficient to provide a first insight into the potential value of an MB. Furthermore, it may have been too difficult for patients with low digital literacy to participate in interviews via video calls, which may have led to selection bias and reduced generalizability.

CONCLUSIONS

This qualitative study showed that both HCPs and patients recognize that an MB could be beneficial and valuable for patients with COPD at high risk of exacerbation, both in the short-term and long-term. In particular, they highlighted the perceived value of an MB in supporting the self-management of patients with COPD. Both HCPs and patients wanted to use an MB for the early detection of exacerbations and did not see major differences in its use in short-term or long-term care. Furthermore, the identified facilitators and barriers to the use and implementation of an MB in COPD patient care, emphasize the need for ongoing research and careful consideration of stakeholders' perspectives. This may ultimately support the successful implementation and adoption of wearable technology in this area of care. The integration of an MB into clinical practice through blended care has the potential to increase overall well-being and health outcomes of patients with COPD by supporting their self-management.

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Data availability

The data are not readily available because participants did not give consent to share data with other parties.

Conflicts of Interest

All authors declare that they have no conflicts of interest. Corsano Health B.V. was not involved in the execution, analysis, or reporting of the study.

Abbreviations

COPD: chronic obstructive pulmonary disease
COREQ: Consolidate Criteria for Reporting Qualitative Studies
GDPR: General Data Protection Regulation
GOLD: Global Initiative for Chronic Obstructive Lung Disease
HCP: health care professional
MB: monitoring bracelet
WMO: Dutch Medical Research Involving Human Subjects Act

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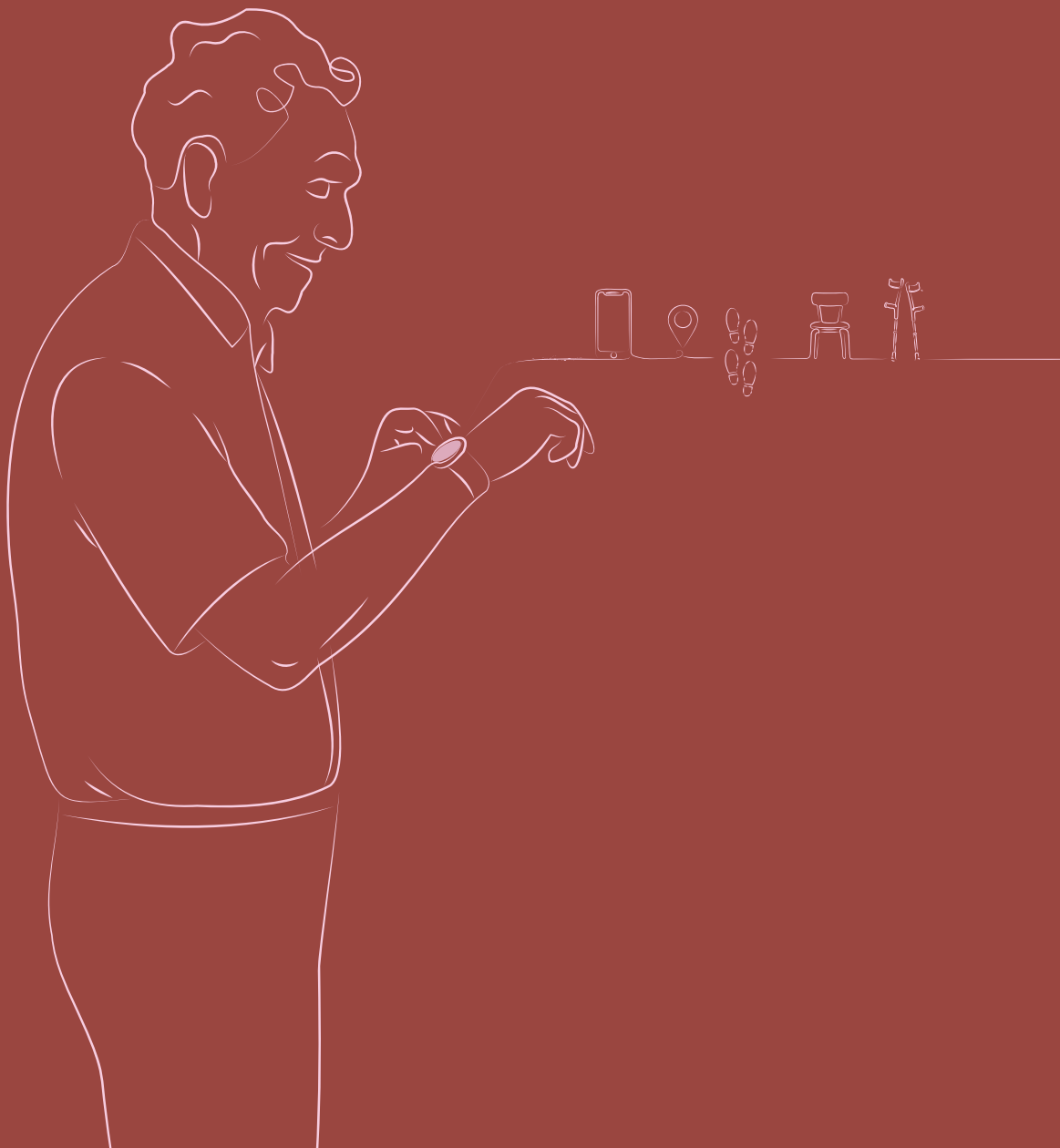
MULTIMEDIA APPENDICES 1 & 2

Link to multimedia appendices

QR code to multimedia appendices



Chapter 3

Adapting a digital monitoring system for self-management to geriatric COPD rehabilitation: a participatory mixed method study

Suzanne Debeij
Eléonore van Dam van Isselt
Marise Kasteleyn
Heleen Krabben
Petra Siemonsma
Wilco Achterberg
Miriam Haaksma

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ABSTRACT

Introduction: Self-management for patients with Chronic Obstructive Pulmonary disease (COPD) is essential in preventing relapse and rehospitalization. This study aimed to adapt a self-management-supporting digital monitoring system that was designed for COPD patients at home, to older patients with COPD and their healthcare professionals during inpatient geriatric rehabilitation. It evaluated feasibility, usability, and adherence based on qualitative and quantitative data collected across three iterations.

Methods: This participatory mixed-methods study, conducted between October 2022 and June 2023, included interviews with patients and focus groups with healthcare professionals on the usability and feasibility of the system. Qualitative data were coded and analyzed using the framework method. Quantitative data from the monitoring system were descriptively analyzed.

Results: Five healthcare professionals and 10 patients participated. Adjustments to the system and its use were made between iterations. Most patients used the system frequently. Insight into energy balance and health status were described as valuable features in a digital monitoring system. Other important aspects were easy initiation and use of the system and integration into the treatment program.

Discussion: While the digital monitoring system and its use underwent various adaptations, further changes such as integration into the treatment program are needed for the system to be usable and feasible during geriatric rehabilitation. To transfer an eHealth intervention for home use to use during inpatient rehabilitation, substantial adaptations and time are required.

Impact: This study highlights the importance of tailored digital health systems, offering guidance on implementing eHealth solutions in complex settings such as geriatric COPD rehabilitation.

Keywords*: Pulmonary rehabilitation, digital health technologies, post-acute care, user-centered design, blended care, agile, eHealth*

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) has a global prevalence exceeding 10% and ranks as the fourth leading cause of death[1, 2]. Smoking is COPD's primary causal factor, and its prevalence increases with age[2]. In the Netherlands, over 33,000 individuals with COPD are hospitalized per year due to an acute exacerbation[3]. An exacerbation is, according to the GOLD guidelines, marked by a sudden worsening of respiratory symptoms that results in additional treatment[4]. Many people who had an exacerbation are readmitted shortly after discharge, with one in ten being readmitted to the hospital within a month, and over three in ten within a year[5]. Each exacerbation has deleterious health effects, such as reducing health status, quality of life, functional status, and increased mortality risk[6]. Consequently, reducing the exacerbation rate, preventing readmissions, and sustaining recovery after an exacerbation are critical to improving outcomes for the population with COPD.

In the post-acute phase, rehabilitation can be offered to improve outcomes after an exacerbation[7]. It focuses on restoring functional abilities or enhancing remaining capabilities for older adults with, possibly various, disabling impairments[8]. This rehabilitation is short-term and is carried out in a therapeutic environment and has a multidisciplinary approach. The rehabilitation treatment program is personalized, consisting of several modules such as control of symptoms, physiotherapy, occupational therapy, and psychosocial interventions[9]. One key objective in geriatric rehabilitation is the optimization of self-management. Enhanced self-management skills improve the recognition and management of an exacerbation, coping responses, and a person's energy management[10]. Optimized self-management for patients with COPD can effectively improve health outcomes, support the transition home after rehabilitation, and contribute to sustainable recovery as well as prevent readmissions[9, 11-13].

eHealth can be used effectively to support self-management and should be considered in continued care to reduce admission rates[14]. A study by van Buul et al. validated an eHealth program called SmartCOPD, aimed at optimizing self-management for community-dwelling people with COPD [15]. This digital monitoring system supports patients and their (informal) caregivers through a symptom diary that alerts them to possible exacerbations and, by tracking and providing feedback on physical activity. Its implementation led to a significant decrease in the number of exacerbations and days admitted to the hospital[15].

Both a symptom diary and feedback on behavior can play an important role in COPD care and enhancing rehabilitation with eHealth[16-18]. Online COPD symptom diaries are frequently incorporated in self-management supporting eHealth tools[17], as symptom monitoring might help to indicate exacerbations and can impact function and quality of life throughout the day[19, 20]. However, evidence on these tools remains inconclusive regarding general effect on health behavior and their ability to detect exacerbations[18, 21-23]. A multidisciplinary approach and social support in the use of eHealth are important for self-management support after discharge from hospital[24].

The adoption of eHealth in older individuals is generally poor and results from studies are inconsistent because eHealth applications often do not match the older individuals' skills, needs, and wishes[25, 26]. Furthermore, eHealth should be adopted not only by older individuals, but also by healthcare professionals who may experience digital literacy issues, barriers to adapting their methods of delivering care and dread investing their time[26, 27]. Personalized support and the involvement of stakeholders, such as patients and professionals, in developing, implementing, and evaluating eHealth interventions can help overcome these barriers and increase usability and feasibility[28, 29]. Personalized support for eHealth and its long-term use can start during inpatient rehabilitation to improve patients' skills and confidence for the transition home. However, knowledge regarding the use of eHealth in this complex setting is scarce[30]. Therefore, this study aims to adapt a digital monitoring system, in co-creation with stakeholders, to the context of inpatient geriatric COPD rehabilitation. The adaptation is evaluated in multiple iterations by qualitative and quantitative measures of feasibility, usability, and adherence.

METHODS

Study design and participants

This study had a mixed-methods participatory design. It incorporates an agile science approach and includes various iterations with interviews including a think-aloud task, and focus groups. The CeHRes roadmap was used to structure the process[29]. The study was declared to be outside the scope of the Dutch Medical Research Involving Human Subjects Act (WMO) by a non-WMO review board of the Leiden University Medical Center (study nr 22-3044).

All participants were recruited from a post-acute, inpatient geriatric rehabilitation center located in a metropolitan area in the Netherlands (Laurens Intermezzo Zuid, Rotterdam). Healthcare professionals (HCPs) and patients were invited to participate. Inclusion criteria for patients were admission to the geriatric rehabilitation ward as result from an acute COPD exacerbation and having access to a smartphone or tablet. Patients were excluded if they had a life expectancy of less than three months or if they showed severe cognitive impairment. HCPs had to be stakeholder as defined in this study to be included. All participants provided written informed consent prior to their participation. Participants did not receive remuneration for participation.

Digital Monitoring System

SmartCOPD is a CE-marked Class 1 digital monitoring system that is designed to recognize signs of an exacerbation in community-dwelling people with COPD. The system was developed by Viduet Health BV (formerly Medicine Men, Utrecht, the Netherlands) with input from patients and stakeholders[31]. The digital monitoring system was compatible on both IOS and Android devices and consisted of two components: a digital exacerbation action plan (DEAP) for recognizing and preventing exacerbations, and a Smartwatch to Monitor patient Activity (SMA). The digital monitoring system required internet connection to function. HCPs could view data from both components through a web-based HCP dashboard. In this study, various aspects and processes of the digital monitoring system were adapted in advance for the geriatric rehabilitation setting. Patients in this study used the digital monitoring system for approximately three weeks during their rehabilitation.

The DEAP, accessible via a standalone mobile application, included three features for this study: a daily question (BASE), a PLUS question, and a Dutch version of the Clinical COPD questionnaire (CCQ). Each questionnaire could be answered when it was available in the mobile application.

- The BASE question was available daily. The question was "*I am experiencing an INCREASE in the following symptoms"* and was followed by checkboxes with eight symptoms of an exacerbation and an option of "*no worsening"*. Based on the answers, patients were assigned to one of four zones and received advice accordingly (Figure 1). In all zones except green, patients were advised to read their COPD action plan and react accordingly. When patients perceived

a decrease in symptoms, they went back into the green zone. HCPs were notified if patients entered the non-green zones.

- The PLUS question had a similar set-up as the base question, was always available, and could be filled in if patients started to experience more severe symptoms. If they indicated a worsening of symptoms, they immediately entered the orange or red zone (Figure 1). The color of the zone was dependent on the symptoms a patient perceived.
- The CCQ was available multiple times a week. The CCQ is a ten-item questionnaire covering three domains of health: symptoms, functional state, and mental state, and has been proven useful and responsive in geriatric COPD rehabilitation evaluation[32, 33]. Answers to the CCQ are scored on a 7-point Likert scale. A higher score on the CCQ indicates lower health status (range 0-6). A score over two is interpreted as impaired health status[33].

The SMA monitored the patient's daily steps, and patients could see their step count on their watch. It also contained a step goal set by HCPs for patients. Patients could also keep track of step counts during the day via a battery-shaped icon displaying their progress: green if the goal was reached, orange if the goal was close, and red if the step count was below target.

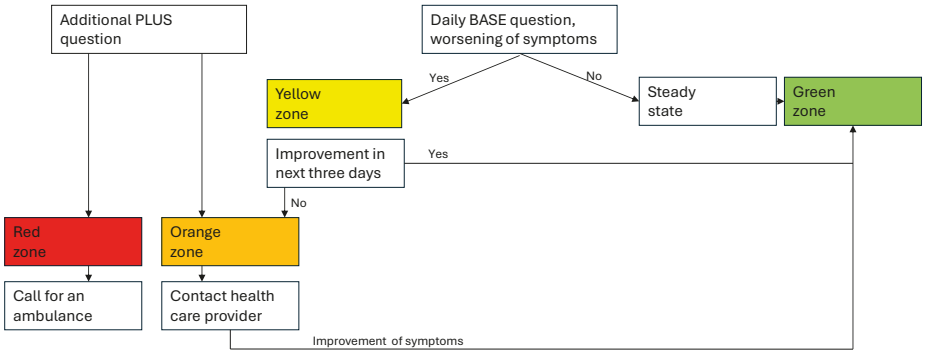

Figure 1. Visualization of the flow in zones of DEAP in the digital monitoring system. Reproduced with permission from van Buul et al. (2021) [15].

Data collection

Qualitative data and quantitative data were collected in parallel.

Qualitative data

Ten persons conducted the qualitative data collection: two female researchers (SD, MH) and eight physiotherapy students (6 female, 2 male). Researchers were experienced in interviewing, students were not. The patients had not met the interviewers before and did not know them; the HCPs had met the interviewers before. Participants were informed about the research objectives. No other people were present during the focus groups and interviews. To assess the digital monitoring system's usability and feasibility, the interviews and focus groups followed a predetermined semi-structured interview guide (Supplemental material 1) based on the CeHRes roadmap and the Optimized User Experience Honeycomb (Supplemental material 2) [29, 34, 35]. The Honeycomb's seven facets shaped the questions to evaluate user experience[34, 35]. The interviews and focus groups were audio-recorded, and the recordings were stored in a secure and restricted data folder at Leiden University Medical Center. The interviewer made notes during the data collection.

The interview included a think-aloud task in which patients used the digital monitoring system and were asked to verbalize their thoughts while performing the task[36, 37]. The patients were asked about, for example, their experience with the digital monitoring system, the added value for their rehabilitation and points for improvement. An example of a question asked is "*How user-friendly do you find the application?*" The focus group included questions relating to the same topics as the interviews. In addition, the focus groups included statements to discuss such as "*I think it is feasible to use SmartCOPD in the treatment program of a patient in geriatric rehabilitation".*

Quantitative data

The quantitative data consisted of baseline characteristics such as age, sex, GOLD stage and USER (Utrecht Scale for Evaluation of Rehabilitation) score[38], data from the questionnaires in DEAP (BASE, CCQ), data from the SMA (step count per part of the day and corresponding step goal) and answers to the System Usability Scale (SUS) questionnaire[39].

Patients answered the SUS questions once after using the digital monitoring system. Responses were collected in an online platform by an HCP. The SUS is a reliable and robust instrument to measure the usability of new ICT systems or products[39]. HCPs were invited to fill out the SUS in an online platform at each iteration. The 10-item questionnaire has a 5-point Likert scale ranging from

"*strongly agree*" to "*strongly disagree*". Total scores can range from 0-100, with higher scores indicating higher usability.

CeHRes roadmap

The CeHRes roadmap comprises five phases and continuous formative evaluation to guide the adaptation of the digital monitoring system. The first three of the five phases of the roadmap and the evaluation were applied in this study (see Figure 2). *Contextual Inquiry* is the first phase; the goal is gaining an understanding of the prospective users, other important stakeholders, the geriatric rehabilitation setting and the weak and strong points of the digital monitoring system. In the next phase *Value Specification*, the values of the key stakeholders are identified and prioritized based on their needs and wishes, and the added value of the digital monitoring system in geriatric rehabilitation is determined. Furthermore, the values are translated into requirements for the digital monitoring system. The third phase is the *Design* phase, in which the technology is adapted, and the usability is tested. See Table 1 for the content of the phases of the CeHRes roadmap within this study. The *Formative Evaluation*, in which the outcomes of the previous phases are checked, and the stakeholder perspective is included, was also covered.

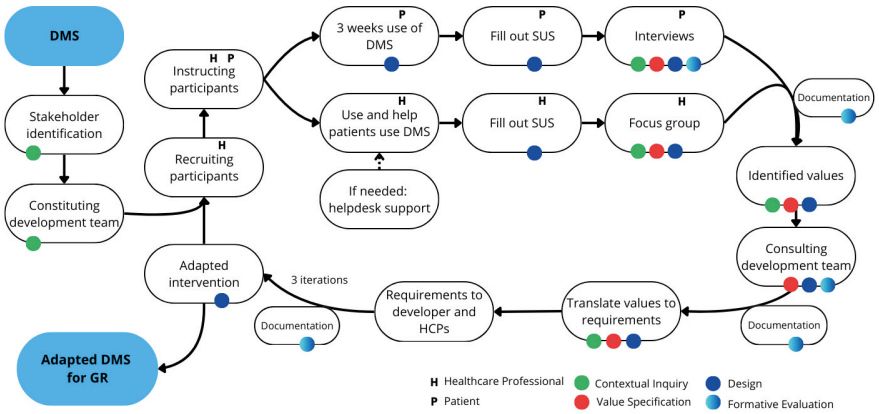

Figure 2. Visualization of the iterative phases of the study. DMS: digital monitoring system; SUS: system usability scale; GR: geriatric rehabilitation; HCP: healthcare professional

Table 1. Research activities per phase of the CeHRes roadmap

Phase	Goals	Set up in research	Deliverable
Contextual Inquiry	Identify stakeholders Describe weak and strong points of current situation (usability & feasibility)	Identification of stakeholders [40] (only in iteration 1) Interview questions about the current situation Focus group questions about the current situation Development team provided future direction	Stakeholder overview Insight into weak and strong points of an iteration (usability & feasibility)
Value Specification	Identify values and supposed added value of the digital monitoring system Prioritize values Translate values into technical requirements	Interview questions regarding needs and wishes (including Think-aloud task) Focus group questions regarding needs and wishes Development team translated values into requirements	Identified values of stakeholders (usability & feasibility) Prioritization of values and translation into requirements for change
Design	Develop and adapt digital monitoring system Test digital monitoring system Test persuasive elements	Requirements are implemented in the digital monitoring system Interview questions on usability based on the optimized user experience honeycomb Focus group questions based on the optimized user experience honeycomb	Insight into usability & feasibility New version of the digital monitoring system to be used in following iteration
Formative evaluation	Check whether outcomes of previous phases have been accounted for in the current phase. Continuously include stakeholder perspectives	Snowballing in stakeholder identification Documentation of interviews, focus groups and made changes Usability testing (Think-aloud task) Preliminary analysis per iteration Check outcomes of previous iteration Check if requirements address the values	Documentation and check-ups Preliminary analysis

Procedure

Three iterations of data collection took place between October 2022 and June 2023. Figure 2 shows the content of the iterations. At the start of the study, stakeholders were identified based on the stakeholder identification process described by van Woezik et al. [40]. After stakeholders were identified, a stakeholder development team was formed to manage the iterative phases of the development process. Next, HCPs were purposively sampled, approached, and informed about participation by a researcher. Participating HCPs then approached eligible patients and informed them of the study with a verbal explanation and an information letter. After signing the informed consent form, a patient participated for approximately three consecutive weeks during inpatient rehabilitation. The first week started with the installation of the digital monitoring system on smartwatch and smartphone. If the HCP or the patient encountered difficulties with the installation or the use of the digital monitoring system, they could reach out to a helpdesk by phone. After the first week, patients received a personalized step goal. For the next period, patients used the digital monitoring system. In the third week, patients completed the SUS once with an HCP. At the end of the three weeks, patients were interviewed. Interviews and focus groups were conducted at the rehabilitation center. HCPs were invited to fill out a SUS each iteration. A focus group with HCPs was held at the end of each iteration.

After iterations one and two, a preliminary analysis was carried out to identify weak and strong points of the iteration, collect values, and map the usability and feasibility of the digital monitoring system for the participants. The development team prioritized these values and translated them into requirements. The requirements were passed on to a developer and the HCPs, who adjusted the digital monitoring system and its use in geriatric rehabilitation accordingly if this was possible in a short period of time. The adapted version for use in geriatric rehabilitation was used in the next iteration.

Data analysis

Qualitative data

The interviews were coded and analyzed according to the principles of the Framework method[41]. First, the audio recordings were transcribed, pseudonymized and not returned to the participant. One researcher (SD) and the students familiarized themselves with the data by checking and supplementing transcripts. After familiarization, a portion of the transcripts

were thematically coded by one researcher (SD) in Atlas.ti 23. The same transcripts were also independently thematically coded in Word by another researcher (MZ) or the students. With these coded interviews, the codebook was developed by SD, who subsequently applied the codebook to the remaining transcripts. If necessary, new codes were added to the codebook. The data were then summarized and illustrated with quotations. Finally, the data were interpreted. The analysis was used to identify key elements and common themes in the interviews. Participants did not provide feedback on the findings. The process was supervised by two senior researchers (LvDvI and MK).

Quantitative data

Non-normally distributed data are described in terms of median and interquartile range. The step count per patient per day is visualized with a line graph. Adherence was operationalized as the percentage of days that steps were recorded (i.e., the smartwatch was worn), the percentage of days that the BASE question was completed in the period between first and last completed question and the percentage of days that the CCQ was filled out. All quantitative data were analyzed using SPSS version 29.

RESULTS

Table 2. Characteristics of participating patients

Patient	Iteration	Sex	Age	GOLD stage	Days in rehabilitation	USER	Comorbidities	CCQ baseline
1	1	M	68	4	58	50	heart failure	2.4
2	1	F	65	4	34	68		-
3	1	F	70	-	35	46	malnutrition	1.9
4	1	M	51	4	21	70		2.3
5	2	F	61	4	37	41		1.1
6	2	F	71	3	34	45		1.4*
7	3	F	63	3	52	57		4.0
8	3	F	61	3	56	49		2.5
9	3	F	61	4	67	47	heart failure, malnutrition	4.1
10	3	F	56	3	38	65		3.2*

-: Missing data; M: male; F: Female; GOLD: Global Initiative for chronic Obstructive Lung Disease; USER: Utrecht Scale for Evaluation of clinical Rehabilitation; CCQ: Clinical COPD Questionnaire; *CCQ at baseline is missing, first recorded CCQ is displayed.

Five HCPs and ten patients participated in the study. Four patients (patients 1-4) and four HCPs participated in the first iteration, two patients (patients 5 and 6) and four HCPs in the second iteration, and four patients (patients 7-10) and two HCPs in the third iteration. The median age [IQR] of the patients was 62 (20) years, eight of them (80%) were female, the median number [IQR] of days in rehabilitation was 38 (46) and their median USER score was 50 (IQR: 29). All patients were in GOLD stage 3 or 4. Patient characteristics are described in detail in Table 2. All patients reported being familiar with technology. They use it mainly in their spare time for contacting others and watching tv or news.

Of the five (80%) participating HCPs, four were female. Two of the HCPs were physiotherapists, one was an occupational therapist, one was a certified nursing assistant, and one was a nurse practitioner. Their ages ranged from 32 to 55 years. They all reported being unfamiliar with the use of eHealth in the treatment of their patients.

Approximately 30 stakeholders were identified. Five of them formed the development team. The team consisted of an occupational therapist, a department head, someone from the purchasing department, an information manager, and a project leader from Viduet.

We describe the results for three time periods that the participants talked about: 1) at the initiation of the eHealth intervention, focusing on experiences during the installation process and related changes that were made between iterations; 2) use of the eHealth intervention during rehabilitation, with a focus on values, facilitators, and barriers to the eHealth intervention; 3) perspectives on the digital monitoring system after rehabilitation, including the possibility of using it at home. The changes made to the system or its use between iterations are described in Supplemental material 3.

Initiation of the digital monitoring system

Most patients and the HCPs described the installation of the platform on their devices as a weak point of the digital monitoring system. This improved over the iterations. In the first iteration, all patients and all involved HCPs described difficulties with the installation process. The installation was mainly carried out by one HCP who felt that the complicated and very time-consuming process made the app less accessible, feasible and usable. Because of the difficulties, the helpdesk was often needed during installation. An HCP in the first iteration stated:

The installation really takes a lot of time, and you frequently get an error message. The helpdesk is easy to reach…. You need an hour with patients to get it all done, because each application has to be linked. (physical therapist, iteration 1)

The development team saw that a change was required in the installation process. They decided to prioritize this requirement by outsourcing the main part of the installation from an HCP to the helpdesk in the second iteration. In addition, further adjustments to the installation process were required after the second iteration. Changes were made such as a technical adjustment to simplify the flow of installation and an adjustment in use to regular calls instead of video calls. After these adjustments, only half of the patients in the third iteration described the installation as a weak point. Patients in iterations two and three described experiencing inconveniences in contact with the helpdesk. Both HCPs also described that the inconveniences in contacting the helpdesk had increased compared to the first iterations. The HCPs felt that the rough start decreased patients' motivation to continue using the app.

On the other hand, the HCPs were positive about the changes made between iterations because these saved them a lot of time. In addition, the other half of the patients in the third iteration experienced a smooth installation process.

It was very easy to install for, even for me, although I don't know anything about it. But I did it over the phone with the person who installs the platform. That went great, so I am smarter than I thought. It was very easy, really good. (patient 8)

Use of the digital monitoring system during rehabilitation

Participants described the values, facilitators, and barriers to using the intervention during rehabilitation. The development team changed the values to requirements when necessary and possible. Participants saw the most value in gaining insight into the energy balance of patients and into patients' health status.

Value: Insight into energy balance

One value of the digital monitoring system for HCPs that we found was having insight into the energy balance of patients. However, HCPs believed that insight into patients' energy balance should not rely solely on step counts, as step tracking may not capture some movements and other activities that also use

energy. Therefore, HCPs felt the SMA did not capture the energy balance well. On the other hand, patients saw value in keeping track of steps and often monitored their step count on their smartwatch throughout the day.

In the first iteration, all patients described the SMA as usable and feasible, stating that they were more aware of their health and their physical activity during the day. In contrast, the step goal was described less positively. Several patients in iterations one and three mentioned that they did not have a step goal or that it did not suit them. In fact, quantitative data from the smartwatch showed that only five out of ten participating patients had a personalized step goal. HCPs thought that this lack of personalized goals was partly due to a change in staff between the first and second iteration. In the third iteration, HCPs mentioned that the personalized step goal felt like a rough estimate. They did not add a personalized step goal because they did not feel it added value.

In the second and third iterations, patients described the added value of seeing their step count and progress in their step count during rehabilitation. However, half of the patients also described that the step count was inaccurately measured and therefore felt less reliable. This barrier was also described by HCPs in all iterations. HCPs further mentioned that a fixed step goal for a patient contradicts what is taught in rehabilitation, namely that not only steps, but all activities (e.g., a doctor visit or ADL) require energy and that patients need to balance their energy throughout the day.

HCPs also expressed concern that the digital monitoring system did not provide a clear clinical picture of a patient because steps were too one-dimensional.

Of course it doesn't show that someone is totally worn-out after washing and dressing, which is what we would really like to see. (nurse practitioner, iteration 2)

Both patients and HCPs also described other points for improvement in the SMA. These include adding oxygen saturation, measuring activities instead of steps, adding how someone feels during the day or adding the Borg scale[42] to provide insight into the patient's perceived burden activities and thus their energy balance. Although the development team felt that adapting the SMA was a priority, they saw no opportunity to make changes in the SMA between the first and second iteration due to the limited time. Between the second and third iterations, the Borg scale was added to the digital monitoring system

to provide more insight into various activities of the patient. The 'bad day' button was added to reduce the step goal accordingly when patients had a 'bad day'. However, only one patient reported using it. HCPs in the third iteration still did not think the SMA was very useful during rehabilitation. If the digital monitoring system were to be developed further, they would like to see a connection between the Borg Scale and the step goal. In this case, the step goal decreases after a patient added a strenuous activity into the Borg Scale.

Quantitative data show that patients had a median step count of 1469 (IQR: 7041) during their rehabilitation (n=8). The line graph shows that the measured step count varied per day and per patient (Figure 3). No clear trend could be derived from the data. Patients 1, 2 and 3 had a period of being isolated in their room due to COVID-19 infection during their rehabilitation. Patient 10 had no step count data due to a failed installation. All patients (n=8) adhered to wearing their smartwatch between 62% and 98% of the days they participated.

Value: Insight into health status

Another value that we found was the value of having insight into a patient's health status provided by DEAP. Barriers to using, and adherence to DEAP were also discussed.

In all iterations, HCPs felt that, within the digital monitoring system, DEAP had the most added value for patients in geriatric rehabilitation with COPD. HCPs described patients using SmartCOPD as being more aware of their health status.

I am really enthusiastic about the COPD action plan [DEAP]. You are really on top of it. Also, patients with that color. You give them insight, so you are actually digitizing the COPD action plan. I think that's fantastic (physical therapist, iteration 3)

In addition, the HCPs indicated that they could use the patients' responses to the DEAP BASE question to personalize patients' therapy and that they themselves were aware more quickly of a patient's symptoms. However, several HCPs in the first iteration found the BASE question unclear and discussed improvement possibilities. The lack of clarity of the BASE question was also mentioned by some patients. They described ambiguity in questions in general, in the DEAP zones or in the corresponding alerts. The development team

changed the value into a requirement and adapted the question after the first iteration. However, some lack of clarity remained.

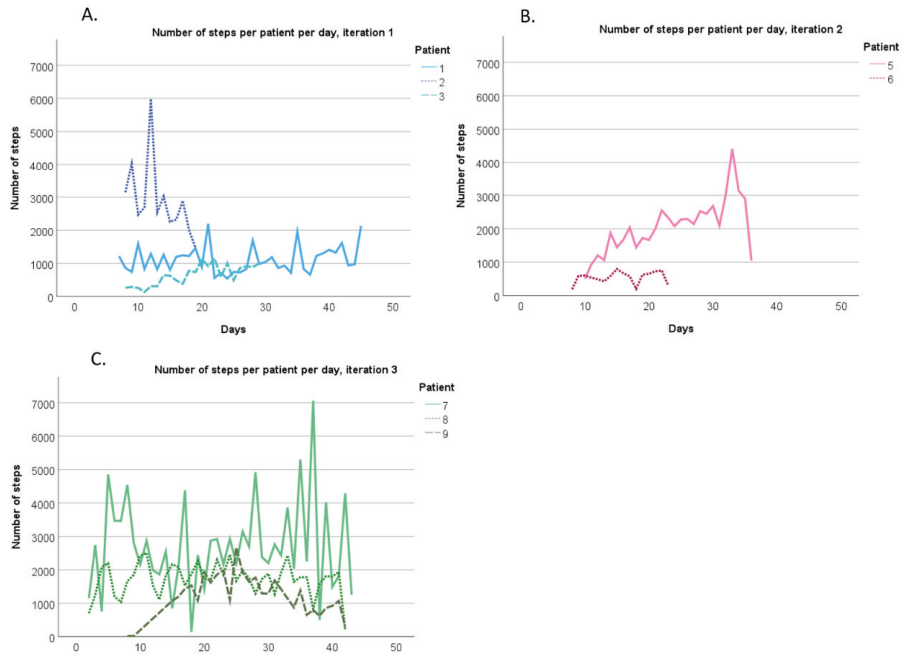

Figure 3. Number of steps during rehabilitation per person per day: (A) in the first iteration, (B) in the second iteration, (C) in the third iteration

Patients also described some other weak points in the DEAP. Some of them felt that the exacerbation risk alert was shown too quickly, or they wished that they could have their questionnaire back after completing it. Finally, a small number of patients did not think the app was desirable because the BASE question was the same every day.

In half of the interviews, patients reported that they answered the DEAP BASE question daily and almost all the patients found the DEAP easy to find and easy to use. They thought the DEAP was feasible. Some patients mentioned the convenience of the digital monitoring system being linked to their paper COPD action plan, or receiving an alert when they had symptoms.

"I do like having it, because it warns you when something is wrong. I like that, it means you do not have to call a doctor right away." (patient 8)

The high adherence patient described in the BASE question was consistent with the quantified measurements of adherence. Four of the ten patients had 100% adherence, three between 80 and 90%, one 53%, and two between 15 and 25%. For one of the last two, the installation was not completed. In addition to adherence, the CCQ showed a variance in adherence ranging from zero completed CCQs to 100% adherence.

Value: Blended care

Another value that we found was the value of offering a digital monitoring system blended into the treatment program, instead of an addition to it.

HCPs discussed not only the content of the digital monitoring system during the focus groups, but also the way it was set up in the rehabilitation center. Both HCPs in the final iteration described that the digital monitoring system was not integrated into the treatment program but used alongside the treatment program. They felt the intervention would have been more useful if it had been adopted by the whole ward or even more widely, rather than being carried out of by a few HCPs, and if it had been integrated into the treatment program. The HCPs in all iterations also described other factors of usage that reduced the accessibility of the platform for HCPs as well as patients. This includes the mentioned inaccuracy of the step count, the change in actively involved HCPs during the research, difficulties in estimating and finding eligible patients, and the patients having other priorities. This reduction in accessibility also reduced feasibility.

Because now, it's sort of a separate thing, like 'Oh, this is a patient, and he happens to have a question. Do we need to respond to that?' Or it sorts of fades into the background, whereas if it's a fixed element in the treatment program, I think we could be more on top of it than we have been so far. (physical therapist, iteration 2).

Some patients experienced a lack of involvement of the HCPs. Slightly less than half of the patients explicitly stated that the use of the digital monitoring system was not discussed much with the HCPs.

General remarks

In addition to the values and barriers mentioned above, participants described some other values and formulated general remarks that influenced the usability and feasibility of the eHealth intervention.

Examples of other values that were mentioned by one or several patients were the added value of measuring heart rate (read from the smartwatch), the feeling of being in control, and the short lines of communication with the HCPs. Apart from these values, most patients indicated having doubts about the added value of the digital monitoring system for their rehabilitation. However, most patients would recommend the system to others even though they thought that it would be beneficial for a different target group (e.g., at the beginning, when you live alone, for younger people). Also, most patients briefly mentioned the design of the system. Most of them reported that the smartwatch was comfortable to wear, and more than half of the patients thought that the app providing DEAP was easy to use, and that the font was clear. In addition, half of the patients felt the DEAP app was user-friendly. However, some patients mentioned a lack of clarity in the general use of the digital monitoring system, which reduced usability. Furthermore, a small proportion felt that the app was not user-friendly or was boring.

So far everything is going really well, it's a positive experience. I just miss a small piece. Other than that, the questions are unambiguous and clear. I can fill it out neatly. And I try to be as, just as honest as possible. (patient 1)

So I fill it out, and the questions disappear, my answers are gone, and I can't find anything again. So, when I open the app now, it's the same as yesterday and the day before and the day before that. It's just a boring app. (patient 5)

HCPs did not describe any additional value beyond those described above. In their opinion, the added value of a digital monitoring system for patients should be mainly in three things: that they are aware of their symptoms, that their activities are visualized throughout the day, and that they learn about the changes to their body due to a recent exacerbation. They did not feel the digital monitoring system provided this. Furthermore, according to both HCPs in the third iteration, the difficulty finding eligible patients also resulted in low integration, making the system less feasible. They indicated that the low eligibility could be due to the age of patients, severity of their disease, social class, education level, and digital literacy in rehabilitation. They felt the system might be better suited for patients in a more stable environment. Therefore, they concluded that, for now, the implementation of the current version of the digital monitoring system in the geriatric rehabilitation setting was not feasible.

Also, HCPs in the first iteration mentioned the complexity of the digital monitoring system dashboard for HCPs. The HCP who mostly used the dashboard in the first iteration felt that the HCP dashboard was not intuitive and that it took a lot of clicks to get where you wanted to go. The development team considered what changes were required, and after these were made, the HCP in the final iteration thought the HCP dashboard was comprehensible and clear. However, the three HCPs who used the digital monitoring system most frequently still felt that the current version was not user-friendly enough to be implemented in geriatric rehabilitation. They thought it was too time-consuming for them and their patients.

Substantial variance in experienced usability was observed among patients, with SUS scores ranging from 7.5 (for the patient whose installation failed) to 97.5. All HCP scores were below 70, ranging from 42.5 to 67.5.

Perspectives on the use of the digital monitoring system after rehabilitation

The possibility of using the digital monitoring system at home after rehabilitation was discussed both in the interviews and in focus groups.

Half of the patients mentioned that it would be useful to use the digital monitoring system at home after rehabilitation. They thought it was mostly useful to stay in contact with the HCPs at the rehabilitation center and to be alerted in case of an exacerbation.

HCPs in the first two iterations also saw value in using the digital monitoring system at home. They thought it would be valuable to teach patients how to use the digital monitoring system in the rehabilitation center so that they could use it at home. The HCPs mentioned that the most usable and feasible part for home use was the continued use of DEAP. In addition, they stated that it would be useful to know what kind of activities patients were doing at home, that the step goal should be adapted to the home setting and that a personalized step goal might be of more value in this setting. HCPs also mentioned that if they use the digital monitoring system at home, patients should be aware that they themselves are in control and must act when needed, not an HCP. HCPs are no longer responsible for patients after rehabilitation. They also discussed who should be responsible for the data provided by the digital monitoring system. They further described some logistical barriers to using the digital monitoring

system at home, such as getting the smartwatch back and the period of time that the digital monitoring system should be used.

In the third iteration, both HCPs discussed whether the digital monitoring system would be more usable and feasible if it was implemented during a stable phase in a patient's COPD, instead of during rehabilitation. They thought that steps might be more beneficial at home, and that the app could be valuable in the stressful transition home if it was more integrated into a person's daily life.

A transition home from here sometimes is of course stressful for people, like 'how am I going to do this at home'. They see bumps in the road. I can imagine that if people are in a more stable situation, so for example a long-term admission of just getting started from the home situation, where all goes relatively well, that that is less stressful for people. (physical therapist, iteration 3)

DISCUSSION

The aim of this study was to adapt a digital monitoring system to the needs and wishes of older individuals with COPD and their HCPs in inpatient geriatric rehabilitation. While the digital monitoring system and its use were adapted in several ways, further changes to both are needed to make the system usable and feasible in the geriatric rehabilitation setting. Professionals were most enthusiastic about the DEAP feature, while patients saw value in tracking step counts.

The HCPs viewed the DEAP as the most promising and valuable part of the digital monitoring system because of its ease of use and the insight it provides into a patient's health status. HCPs felt this was a usable and feasible feature. A narrative review emphasizes this added value, highlighting that patient experienced outcome measures significantly impact outcomes valuable for both patients and health care providers[43]. Unfortunately, the study that showed a significant decrease in the number of exacerbations in patients who used the digital monitoring system compared to patients who did not[15], did not provide details on which aspects of the digital monitoring system contributed to this effect, nor did they elaborate on user perspectives. There is no consensus on the use of eHealth support for self-management by tracking health status during geriatric rehabilitation. Some studies state that eHealth programs that track symptoms in patients with COPD are both feasible and usable[44-46],

while others are less convincing[18, 24]. Additionally, patients may have been less convinced because of the design of the system (as could be seen in low SUS scores), or because patients who believe that they are aware of their symptoms may not see any benefit to intensive monitoring[47]. Perhaps the use of a self-management monitoring system is only feasible for a selection of patients with COPD during inpatient rehabilitation.

The finding that eHealth support for physical activity can have positive effects in patients with COPD[48] is consistent with the value described by patients in the present study. The HCPs' wish for a more multidimensional perspective, by expanding the step count with other factors such as heart rate, saturation or perceived exertion rate, is shared by others in various settings to gain more insight into energy costs[49-52]. To our knowledge, such multidimensional accuracy has not yet been established in a wearable device, certainly not for people in geriatric rehabilitation. However, energy management techniques may be of particular importance for people with low energy levels.

The technical issues experienced by participants can be divided into two parts. First, they described reduced confidence in the step count due to inaccurate measurement, making it less usable. This is in line with other literature[45, 53]. The inaccuracy of the measurement could be increased due to sensor placement, possible gait abnormalities, slow walking speed, functional limitations, and different body morphologies[54, 55]. Secondly, due to difficulties in the installation process, the system was not easy to use initially, which reduced its feasibility. Both technical and credibility issues have been described as major barriers to the use of eHealth interventions for COPD management[56]. However, technical installations at the beginning might be described as a smaller barrier when patients use a device for a longer period.

Although blended self-management interventions may potentially improve health outcomes in patients with COPD[14], the digital monitoring system was not optimally integrated into the inpatient geriatric rehabilitation program. This may be due to the small number of HCPs involved and their lack of experience with e-Health. eHealth programs that successfully combine eHealth and non-eHealth treatment can complement each other and are more beneficial in geriatric rehabilitation than programs that use it as addition to the treatment[30, 48]. This preference is also described by prospective users of eHealth in geriatric rehabilitation[57] and patients with COPD[58]. Additionally, the integration of the information from the digital monitoring system in patients' medical records

could increase accessibility to the data[26], which might also increase ease of use, and can increase quality of care[59] . If a digital monitoring system is more integrated into the treatment with more health status indicators, is easier to use from the start and measures accurately, the system may be a better fit for inpatient geriatric rehabilitation.

Strengths and limitations

Following the CeHRes roadmap, this study conducted multiple iterations of qualitative and quantitative data collection. The multiple iterations and different research methods provided more in-depth insight into the participants' perspectives and allowed for reflection on the changes that were made over time. In addition, the use of the User Experience Honeycomb model made it clear to the development team which values should be prioritized for change between iterations. This research also had some limitations that should be mentioned. Because this was a single-center study, the results may be less generalizable to other settings or countries. Also, the short time between iterations influenced the adjustments that could be made, resulting in fewer adjustments than desired. Moreover, it was difficult to find eligible patients, which resulted in a small sample size and thus less robust evidence. The small sample size could be due to reasons such as “empty beds” in the rehabilitation center or a target group that was too vulnerable to participate, which may be attributed to geriatric challenges. Participants who chose to take part might have had a greater interest in eHealth, potentially introducing selection bias. However, the critical feedback provided by the patients suggests this was not the case. Besides, no medical practitioner was included as HCP which might show a lack of practitioner perspective. However, the role of the medical practitioner in this setting was minimal because the nurse practitioner acts in the role of medical practitioner in this setting. Finally, there were continuity issues due to COVID-19 and changes in the HCP team which might influenced the use of the digital monitoring system for some participants.

CONCLUSION

This study highlights the aspects that should be considered when transferring a digital monitoring system for COPD self-management to a complex setting like inpatient geriatric COPD rehabilitation. Professionals were most enthusiastic about the DEAP feature, whereas patients saw value in tracking their step count. After several iterations with adaptations to the system and its use,

further changes are needed for it to be usable and feasible in this specific setting. For successful adoption, the system must be easy to use from the start, it must measure accurately, and there must be sufficient support and knowledge in the entire team. In addition, the digital monitoring system should be integrated into the rehabilitation process to complement it. The differences in perspectives of different stakeholders underline the importance of involving all stakeholders. In future research, the DEAP and SMA could be further adapted to inpatient geriatric rehabilitation to be usable and feasible. Additionally, a larger sample across various geriatric rehabilitation centers, a longer study duration, and an expansion of objective measures, such as assessments of symptom improvement, are recommended. It should be recognized that potentially major adaptations and therefore multiple iterations are needed to adapt an eHealth intervention to another setting, especially to a difficult context as geriatric rehabilitation. Finally, stakeholders' perspectives on implementing not just an eHealth program, but a multidimensional blended-care program to support self-management during inpatient geriatric rehabilitation should be explored.

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ORCID iDs

Suzanne M Debeij https://orcid.org/0000-0002-4243-5075
Eléonore F van Dam van Isselt https://orcid.org/0000-0002-5584-6295
Marise J Kasteleyn https://orcid.org/0000-0001-7751-7516
Heleen V Krabben https://orcid.org/0009-0006-2571-3121
Petra Siemonsma https://orcid.org/0009-0007-3537-5354
Wilco P Achterberg https://orcid.org/0000-0001-9227-7135
Miriam L Haaksma https://orcid.org/0000-0002-3518-9152

Ethical considerations

The study was declared to be outside the scope of the Dutch Medical Research Involving Human Subjects Act (WMO) by a non-WMO review board of the Leiden University Medical Center (study nr 22–3044).

Author contributions

Suzanne M Debeij: conceptualization, data curation, formal analysis, investigation, project administration, visualization, writing—original draft. Eléonore F van Dam van Isselt: conceptualization, funding acquisition, methodology, supervision, validation, writing—review and editing. Marise J Kasteleyn: conceptualization, funding acquisition, methodology, validation, writing—review and editing. Heleen V Krabben: conceptualization, investigation, software, writing— review and editing. Petra Siemonsma: conceptualization, methodology, writing—review and editing. Wilco P Achterberg: conceptualization, methodology, writing—review and editing. Miriam L Haaksma: conceptualization, funding acquisition investigation, methodology, supervision, validation writing—review and editing.

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Declaration of conflicting interests

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Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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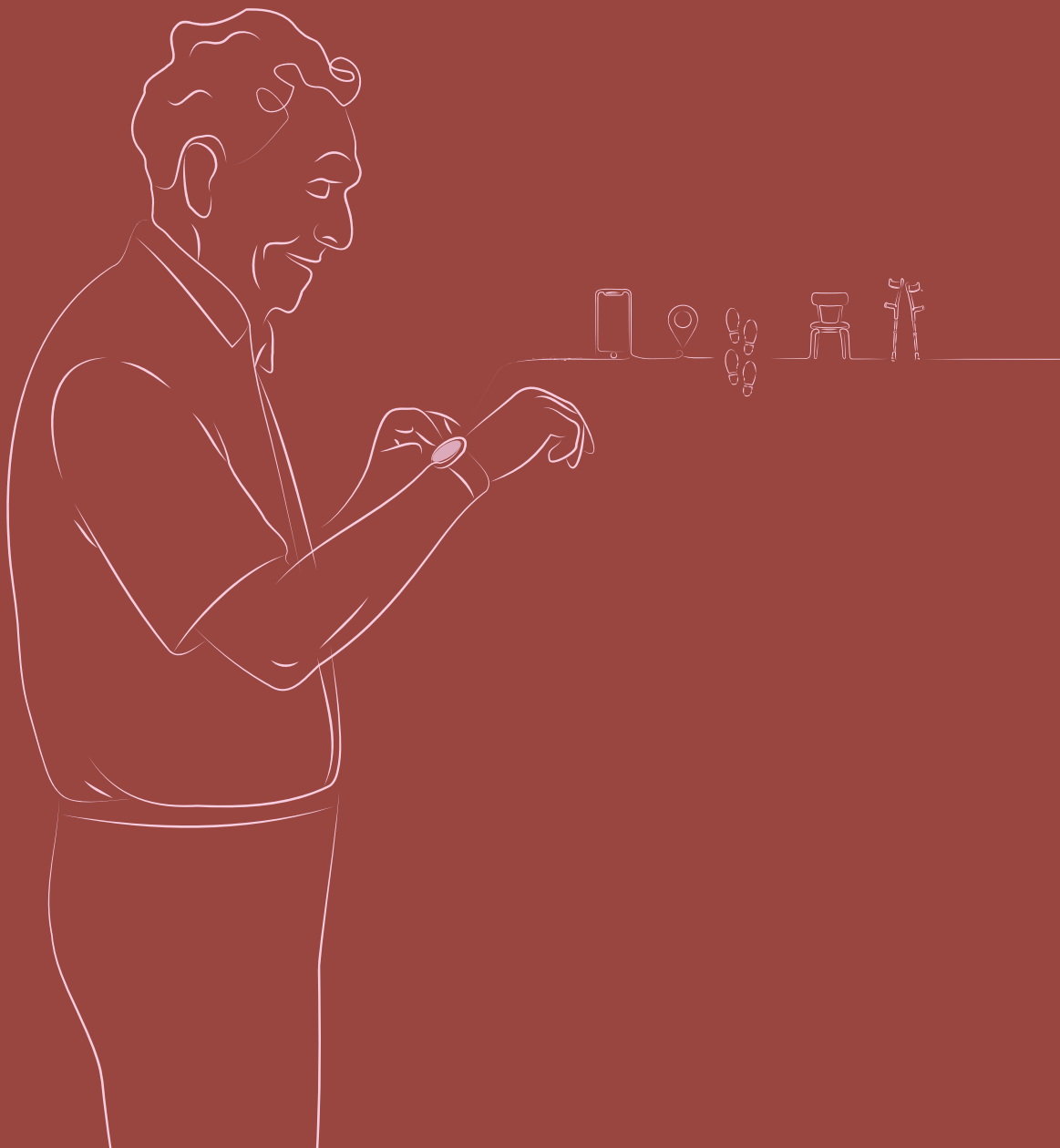
SUPPLEMENTAL MATERIAL

Link to supplemental material

QR code to supplemental material



Chapter 4

Does objective feedback decrease sedentary behavior in geriatric rehabilitation? A systematic review

Suzanne Debeij
Miriam Haaksma
Peter van de Hoef
Wilco Achterberg
Eléonore van Dam van Isselt

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ABSTRACT

Objective: To assess the effectiveness of interventions using feedback from objective measurements to reduce sedentary behavior in older adults during rehabilitation.

Data source: Cochrane Library, Web of Science, PubMed, Embase and Emcare were systematically searched for controlled trials in May 2023.

Study inclusion and exclusion criteria: Studies in post-acute settings involving older individuals, providing feedback as part of the intervention and reporting effects on sedentary behavior were included.

Data extraction: Study characteristics, aim, methodology, intervention content, and outcome measures with effect sizes relating to sedentary behavior were extracted.

Data synthesis: A narrative synthesis was used to describe the data.

Results: Eleven studies with diverse methods and reported outcomes were included. Feedback was focused only on sedentary behavior (one study), on sedentary behavior and physical activity (four studies), or only on physical activity (six studies). All studies showed high bias risk in at least one quality assessment domain. Six studies reported a significant decrease in sedentary behavior, while five reported no effect. No harms were reported.

Conclusion: The effect of feedback-based interventions on sedentary behavior in geriatric rehabilitation remains inconclusive. Interventions differed considerably in content and methodology, and high-quality evidence is lacking. Future research should focus on improving research methodology, optimizing strategies to reduce sedentary behavior and finding the minimum reduction of sedentary behavior required to create a clinically relevant difference.

Keywords: *physical activity, post-acute care, older people, eHealth, remote (patient) monitoring*

KEY POINTS

- Although some studies indicate a (small) reduction in sedentary behaviour following interventions with objective feedback for older individuals in rehabilitation, effects remain inconclusive.
- Interventions to decrease sedentary behaviour differ considerably in content and methodology.
- Despite substantial evidence on the health risks associated with sedentary behaviour, there is a lack of high-quality studies on feedback to reduce sedentary time during rehabilitation.

INTRODUCTION

Older individuals with disabling impairments due to stroke, exacerbation of COPD, a hip fracture, or other causes can be admitted to a rehabilitation department to improve their health. This type of post-acute care is an effective, patient-centered multidisciplinary approach, in which evaluative, diagnostic, and therapeutic interventions are integrated in a treatment plan[1, 2]. The tailored rehabilitation treatment plan aims to restore functional abilities, improve functional capacity, enhance social engagement, and elevate overall quality of life[1, 3].

The older individuals in rehabilitation are encouraged to engage in physical activity to regain functional performance. However, they often do not have the capability to engage in physical activity by themselves or are unable to adhere to the activities[4]. Hence, patients in rehabilitation spend much of their time being sedentary[5, 6]. High sedentary time can have hazardous health effects such as increased risk of cardiometabolic conditions, and premature mortality[7]. Sedentary behavior can be defined as "any waking behavior characterized by an energy expenditure ≤1.5 Metabolic Equivalent of Task while in a sitting, reclining or lying posture"[8]. To describe sedentary behavior, for example, the total amount of sitting time, duration of sedentary breaks and length of uninterrupted bouts spent sedentary are used[9]. Particularly the latter tends to be detrimental to health[10]. Sedentary behavior differs from physical inactivity, as someone who sits most of the day, can still meet the WHO guidelines on the recommended amount of physical activity[7, 11]. Nonetheless, to counteract the risks of a high sedentary time, exponentially more time should be spent on physical activity, which is not feasible for older individuals with impairments[12]. Decreasing or changing the pattern of sedentary time may be a more feasible goal for these individuals to start health behavior change[7, 13].

There are numerous models and techniques to guide or describe behavior change. Michie et al. (2013) created a cluster-divided taxonomy for behavior change techniques[14]. These clusters can be incorporated in existing behavior change models such as the behavior change wheel[14, 15]. One of the clusters of behavior change techniques is 'feedback and monitoring' and comprises techniques including feedback on behavior and self-monitoring of behavior[14]. Aspects from this and other clusters are known to reduce sedentary behavior in adults and older adults[16-19].

Feedback and self-monitoring on objectively measured sedentary behavior can be provided and supported by eHealth, for example, on websites, in applications, and via wearables such as smartwatches and smartphones. In addition, a wearable or other forms of eHealth can be used independently of a healthcare provider which may increase access to services, save time and reduce costs[20]. Wearables could sense movement in the older people in rehabilitation objectively and unobtrusively via accelerometers. The accelerometers give more reliable data on sedentary time and other movement behaviors than self-reported data, which often underestimate the true value[21]. The obtained data can be transformed immediately into visual graphics, which can give the caregiver and patient insight into the actual behavior. The advantages of eHealth provide interesting possibilities to reduce sedentary behavior. Both in a community-dwelling setting and a hospital setting, eHealth interventions are shown to decrease sedentary time in older adults when compared with control conditions[17, 22]. However, in a geriatric rehabilitation population, the effect of eHealth interventions with feedback to decrease sedentary behavior is still unclear. This systematic review aims to assess the effectiveness of interventions using feedback based on objective measurements to decrease sedentary behavior of older adults in geriatric rehabilitation.

METHODS

Data sources

For this systematic review, Cochrane Library, Web of Science, PubMed, Embase and Emcare were searched on May 30 and May 31 of 2023. The systematic review is reported based on the PRISMA 2020 guidelines and is pre-registered in PROSPERO (protocol number: CRD42023428935)[23, 24].

Inclusion and Exclusion Criteria

To be included in this review, studies had to be a randomized controlled trial or have a (quasi)experimental design. Studies were included if providing feedback from an objective measurement was part of the intervention, the intervention started within three months after an acute-care event and had objectively measured sedentary behavior as operationalized in the CROSBI consensus study (sedentary time, breaks and bouts and the number of transitions) as primary or secondary outcome[9]. Furthermore, studies had to include older individuals (mean age 55 years or older). Studies were not excluded based on study quality. The complete search string can be found in supplemental material 1.

Data extraction and synthesis

All titles and abstracts identified by the search were uploaded in the systematic review management tool Covidence and duplicates were excluded. The title and abstracts of the potentially relevant studies were independently screened by two researchers (SD and MH). Next, the same researchers obtained and reviewed full texts to finalize inclusion. Disagreements between researchers were discussed until consensus was reached. If consensus could not be reached, a third researcher (LD) was consulted.

The first part of the data extraction (7 studies (64%)) was conducted independently by two researchers (SD and MH). The remaining data extraction (4 studies (36%)) was carried out by one researcher (SD) who discussed uncertainties with another researcher (MH). Full data extraction can be seen in supplemental materials 2 and 3. Participants' demographics, study aim, design, method, intervention content, and outcome measures and effect sizes relating to sedentary behavior were described in a narrative synthesis.

Quality assessment

The quality of the outcomes in the included randomized studies was assessed per outcome using the Cochrane risk of bias tool for randomized controlled trials (RoB2)[25]. The quality of outcomes in the non-randomized studies was assessed using The Risk Of Bias In Non-randomized Studies – of Interventions (ROBINS-I) assessment tool[26].

RESULTS

Study selection

The search identified 6231 studies. The PRISMA flowchart in figure 1 shows the results obtained at various stages. After exclusion based on title and abstract, 52 studies remained. With full text screening, another 41 studies were excluded. Finally, 11 studies were included in this review. A third researcher was needed to reach consensus in two cases. In one other case, the author of a study was contacted to clarify eligibility of the study.

Study characteristics

Nine of the eleven (82%) included studies were randomized controlled trials[27-35] and two (18%) were historically controlled trials[36, 37]. As shown in Table 1, four of the included studies were conducted in a rehabilitation

setting[29, 30, 32, 34], four in a hospital setting[31, 35-37], two during hospitalization and after discharge[27, 28], and one in a community setting[33]. Two of the included articles were based on the same intervention study and had partial overlap in participants[27, 28]. The difference between these articles was the follow-up time of the intervention.

Three of the studies included participants with a cardiac-related diagnosis[33-35], two with stroke[27, 28], two with joint-related diseases[30, 37], two with a diverse participant group[32, 36], one with participants with mobility issues[29] and one with pulmonary diseases[31]. The study duration varied from under one week[31] to over six months[28, 29, 34]. The sample size across the studies ranged from 49 to 324 participants. The mean age ranged from 58 years[36] to 76 years[29]. All study characteristics are reported in Table 1.

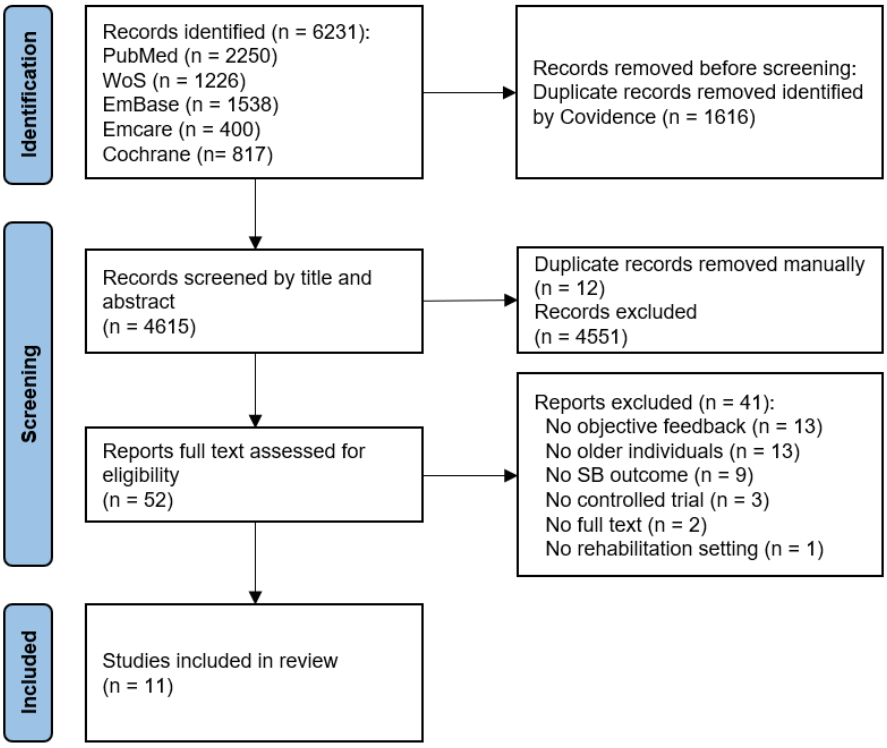

Figure 1. PRISMA flow diagram of search strategy results

Interventions

One study described how the intervention was designed together with patients and provided feedback only on sedentary behavior (table 2)[35]. The other studies simply described the intervention, not how it was constructed. Four studies described interventions that provided feedback on sedentary behavior and physical activity[27, 28, 31, 32] and six provided feedback only on physical activity (table 1)[29, 30, 33, 34, 36, 37]. Feedback frequency varied from continuous feedback available throughout the day to feedback twice a week. The duration of the intervention period varied as well, from a few days only in a clinical setting[31, 37] to up to a full year both in the clinical setting and after discharge[34]. The form in which feedback was provided also varied between studies. Ten studies described feedback being given by a digital device[27-29, 31-37]. Six of these studies also incorporated feedback from a professional in the intervention[27-29, 32, 35, 37]. The feedback from professionals was provided via phone calls in four studies[27, 28, 32, 35] in-person in two studies[29, 37] and via both routes in two studies[27, 28]. In one study, feedback was not provided by a digital device directly, but only via graphic visualization during the physical activity counselling sessions[30]. Furthermore, the feedback was discussed or evaluated with caregiver(s) in eight studies[27, 28, 30, 32, 34-37]. The other three studies did not set-up the intervention as blended-care but used feedback as an addition to the care-pathway[29, 31, 33].

Nine different types of sensors were used to objectively measure sedentary behavior, as described in table 2. The ActivPAL[29, 32], ActiGraph GT3X[33, 34] and Active Style Pro HJA 570-C[27, 28] were used in two studies. Other sensors - Step Activity Monitor 3.0, Activ8, accelerometers in medical Band-Aids, ActivPAL3 and MOX activity monitor - were used in one study.

Study quality

The results of the quality assessments are presented in figure 2. Because multiple outcomes within one study scored the same risk level in all domains of the quality assessment, only one assessment per study is shown. Although four RCTs scored low risk in four out of five domains[31, 32, 34, 35], all included studies scored an overall high risk of bias. The most frequent shortcoming was seen in the domain *missing outcome data*, where only one study scored a low risk of bias[35]. By contrast, the domain *measurement of the outcome* scored low risk in all studies. In the domain *deviations from the intended interventions* two studies scored a high risk[29, 35]. Atkins et al. (2019)[29] reported a contamination of study results, because some participants in the intervention group were

aware of their step count. Van Bakel et al. (2023)[35] also reported on the risk of contamination between intervention and control group. Furthermore, three studies scored low risk in three domains[27-29] and only one study scored a high risk in more than one of the domains[30].

The overall score of the quality assessment of both historically controlled trials was serious[36, 37]. Both studies scored a serious risk in the domains of *confounding* and *selection of the reported results*. Further, both did not control for all the important confounding domains (for example multimorbidity). In the domain of *bias due to selection of the reported results*, it was likely that reported estimates in both studies were selected from multiple analyses.

Effect of feedback on sedentary behavior

Studies operationalized sedentary behavior outcomes differently. The most frequently reported outcome was the change in sedentary behavior/time (55%)[27, 28, 33-36]. Details can be found in table 3. As two RCTs failed to report a between-group comparison[30, 33], a distinction has been made between studies that reported differences between intervention and control groups, and studies that only reported differences within intervention and control groups.

Table 1. Characteristics of included studies

Author (year)	Country	Design	Setting	Diagnosis	Study duration	Sample size	mean age	%female
Ashizawa et al. (2022)[28]	Japan	RCT	Hospital and post-discharge	Stroke	hospitalization + 3 months	61	71	34
Ashizawa et al. (2023)[27]	Japan	RCT	Hospital and post-discharge	Stroke	hospitalization + 6 months	86	72	33
Atkins, Canell and Barr (2019)[29]	Australia	RCT	Subacute hospital rehabilitation unit	Mobility	± 1 month (admission - discharge)	78	76	59
Brandes et al. (2018)[30]	Germany	RCT	Inpatient rehabilitation	Joint	± 3 weeks + 6 months	49	70	53
Conijn et al. (2020)[36]	the Netherlands	HCT	Hospital	Diverse	hospitalization + 1 month	94	58	44
Dall et al. (2019)[31]	Denmark	RCT	Hospital	Pulmonary	1 - 7 days	93	73	51
Hassett et al. (2020)[32]	Australia	RCT	Neurological inpatient rehabilitation	Diverse	6 months	300	72	50
Ozemek et al. (2020)[33]	United States	RCT	Phase III maintenance CR program	Cardiac	3 months	74	61	23
Ter Hoeve et al. (2018)[34]	the Netherlands	RCT	Outpatient cardiac rehabilitation center	Cardiac	3 months (+ 9 months aftercare)	324	59	20
van Bakel et al. (2023)[35]	the Netherlands	RCT	Hospital	Cardiac	3 months	212	63	23
van Dijk - Huisman et al. (2020)[37]	the Netherlands	HCT	Hospital	Joint	median 3 days	97	66	43

RCT = randomized controlled trial, HCT = historically controlled trial

Table 2. Intervention and measurements from included studies

Author (year)	Description of intervention	Control group treatment	Feedback				Sensor for outcome measurement
			Duration	*Provided via*	*Frequency*	*Given on*	
Ashizawa et al. (2022)[27]	During hospitalization: educational pamphlet on reducing SB, goal setting for SB after discharge and self-monitoring of SB and step count. After discharge: self-monitoring of SB and step count, motivational stickers and phone calls for encouragement and feedback	During hospitalization: educational pamphlet on increasing PA, self-monitoring of step count. Feedback on checklist once a week After discharge: self-monitoring of steps	hospital-ization + 3 months	Active Style Pro HJA-750, and by professional (by phone or face-to-face)	Daily by self-monitoring, Once a week from professional during hospitalization, once every two weeks after hospitalization	SB, PA, and step count	Active Style Pro HJA-750C
Ashizawa et al. (2023)[28]	During hospitalization: educational pamphlet on reducing SB, goal setting for SB after hospital discharge and self-monitoring of screen time and step count After discharge: self-monitoring of screen time and step count, motivational stickers and phone calls for encouragement and feedback	During hospitalization: educational pamphlet on increasing PA, self-monitoring of step count. Feedback on checklist once a week After discharge: self-monitoring of steps	hospital-ization + 3 months	Active Style Pro HJA-750C, and by researcher (by phone or face-to-face)	Daily by self-monitoring, Once a week from professional during hospitalization, once every two weeks after hospitalization	SB and step count	Active Style Pro HJA-750C

Table 2. Intervention and measurements from included studies (continued)

Author (year)	Description of intervention	Control group treatment	Feedback				Sensor for outcome measurement
Atkins, Canell and Barr (2019)[29]	An exercise program, feedback from the pedometer and small phrases of encouragement	Usual care and an exercise program, estimation of distance walked each day	± 1 month (admission - discharge)	Yamax Digiwalker SW200 and by family and nursing staff	Continuous feedback and small phrases of encouragement	Step count	ActivPAL Yamax Digiwalker SW200
Brandes et al. (2018)[30]	Encouragement to increase daily step count by 5%, PA counselling twice a week to encourage patients to use restored walking capabilities	Standard rehabilitation	± 3 weeks (inpatient rehabilita-tion)	Graphical visualizations of steps taken shown by PA counsellors	Twice a week in a counselling session	Step count	Step Activity Monitor 3.0 (SAM 3.0)
Conijn et al. (2020)[36]	A multicomponent intervention which included paper and digital information about the importance of PA, an exercise movie, an activity planner, a pedometer and a wearable activity tracker, personal activity coaching and access to a tailored digital exercise program	Usual care	hospital-ization + 1 month	Fitbit Flex and pedometer	Continuous during hospitalization and 1 week after discharge	PA and step count	Activ8

Table 2. Intervention and measurements from included studies (continued)

Author (year)	Description of intervention	Control group treatment	Feedback				Sensor for outcome measurement
Dall et al. (2019)[31]	Feedback on time spent lying in bed, sitting, standing, and walking via an app on a tablet on bedside table. The app contained 'smiley-faces' in different colors. Feedback was visible for patients, visitors, and healthcare personnel.	Usual care	1 - 7 days	An app connected to 2 small tri-axial accelerometers embedded in medical Band-Aids	Continuous	Time bedridden, sitting, standing, and walking	2 small tri-axial accelerometers embedded in medical Band-Aids
Hassett et al. (2020)[32]	Tailored digitally-enabled rehabilitation with exercises, remote monitoring and communication, and a fall prevention brochure	Usual care, prescription of repetitive exercises, tailored management, and a fall prevention brochure	6 months	Activity monitor (Fitbit, Garmin), apps and from therapist (by phone)	Continuous and by phone as required	Performance (dependent on device used; PA, SB or other)	ActivPAL
Ozemek et al. (2020)[33]	PF group: weekly goal to increase PA by 10%, if goal was not met the goal was maintained. Weekly booklets to increase PA. PF+MM group: additional to PF intervention receiving a newsletter on their (not) accomplished PA goal.	Usual care, recommendations to perform home exercises on ≥2 non-CR days	3 months	Liferecorder PLUS, and via newsletter	Continuous, write down 4 times a day	PA goal (step count)	Actigraph GT3X

Table 2. Intervention and measurements from included studies (continued)

Author (year)	Description of intervention	Control group treatment	Feedback			Sensor for outcome measurement
Ter Hoeve et al. (2018)[34]	3 group PA counselling sessions, pedometers for daily PA feedback and goal setting with physical therapist, booklet with assignments, information on goal setting, barrier identification and relapse prevention, information about breaking up SB time. In aftercare 3 sessions of PA and counselling	Usual care, educational sessions, group counselling if indicated, information about general health benefits of PA, no aftercare	3 months (+ 9 months aftercare)	Yamax Digiwalker SW200, self-monitoring	Continuous during CR, 3 times during after-care	PA (step count), aerobic capacity	Actigraph GT3X
van Bakel et al. (2023)[35]	Patient education, goal setting, motivational interviewing with coping planning, (tele) monitoring	Usual care	3 months	Web-based dashboard, smartphone application, vibrotactile feedback from Activ8 and professional (by phone)	Continuous, and (bi)weekly telephone coaching	SB and ST	ActivPAL3

Table 2. Intervention and measurements from included studies (continued)

Author (year)	Description of intervention	Control group treatment	Feedback				Sensor for outcome measurement
van Dijk - Huisman et al. (2020)[37]	Feedback for patient and physiotherapist on time spent standing and walking, feedback on functional recovery assessment, personalized exercise program	Usual care	Median 3 days	Smartphone application coupled with MOX activity monitor and by professional	Continuous	Time spent standing/ wal-king	MOX activity monitor

SB = sedentary behavior, PA = physical activity, PF = pedometer feedback, PF + MM = pedometer feedback + motivational messaging, IPAQ = International physical activity questionnaire, CR = cardiac rehabilitation

Differences between intervention and control

Four of the nine studies that compared outcomes between intervention and control group reported a significant effect on sedentary behavior[27-29, 37]. As shown in table 3, only in the intervention of van Bakel et al. (2023) feedback was focused solely on sedentary time[35]. The authors reported a decrease of 0.4 hours/day more in the intervention group than in the control group, which was non-significant.

However, the intervention was described as feasible and promising because it reduced the odds of sitting longer than 9.5 hours/day. Two of the four studies that provided feedback on both physical activity and sedentary behavior reported even more positive results; both reported a reduction of almost 8% of sedentary time in the intervention group post intervention[27, 28]. These two studies from Ashizawa et al. concluded that an approach that encourages sedentary behavior reductions is more effective than an approach that promotes an increase in physical activity for patients with minor ischemic stroke. However, the third study with an intervention that provided feedback both on physical activity and sedentary behavior, the study of Dall et al. (2019), reported an increased sitting time of 52 minutes/day in the intervention group[31]. Nevertheless, the total time spent in bed was 70 minutes/day less in the intervention group. Since both differences were not significant, the study did not report the intervention as effective. The fourth study reported a non-significant mean reduction of less than three sit-to-stand transitions in the intervention group compared to the control group[32].

The other four studies describe interventions in which participants received feedback on various forms of physical activity[29, 34, 36, 37]. Ter Hoeve et al. (2018) concluded that the intervention with counselling sessions was not successful in changing sedentary behavior, as the intervention group and control group barely showed a difference in sedentary time (0.39% (-.82, 1.59))[34]. Conijn et al. (2020) did not report on change over time and described that the intervention group tended to spend less time sedentary during hospitalization, but not in the first week after discharge while they still followed the intervention[36]. They reported that their results should be interpreted with caution, as they struggled

with methodological issues such as a high drop-out rate. The remaining two studies also did not report on change over time but did report a significant effect between the control group and intervention group on the sedentary behavior outcome in the measured period[29, 37]. The median time spent upright

was 0.55 hours higher than the median of the control group[29]. Van Dijk-Huisman et al. (2020)[37] reported that the intervention group was 28.4 minutes more active than the control group.

Outcomes compared pre-post within a group

Two studies reported pre-post results within groups[30, 33] instead of between-groups comparisons. Both interventions contained feedback on PA. The study of Brandes et al. (2018)[30] reported a statistically significant decrease of 54 inactive minutes from onset to six months post-rehabilitation in the intervention group. The decrease of 29.3 minutes in the control group over the same time period was not significant. The mean duration of inactive bouts and maximum duration decrease in both groups. The study of Ozemek et al. (2020)[33] did report a significant decrease in sedentary time of 2.6%, or 22.4 (12.8) minutes in the intervention group that received feedback using a pedometer.

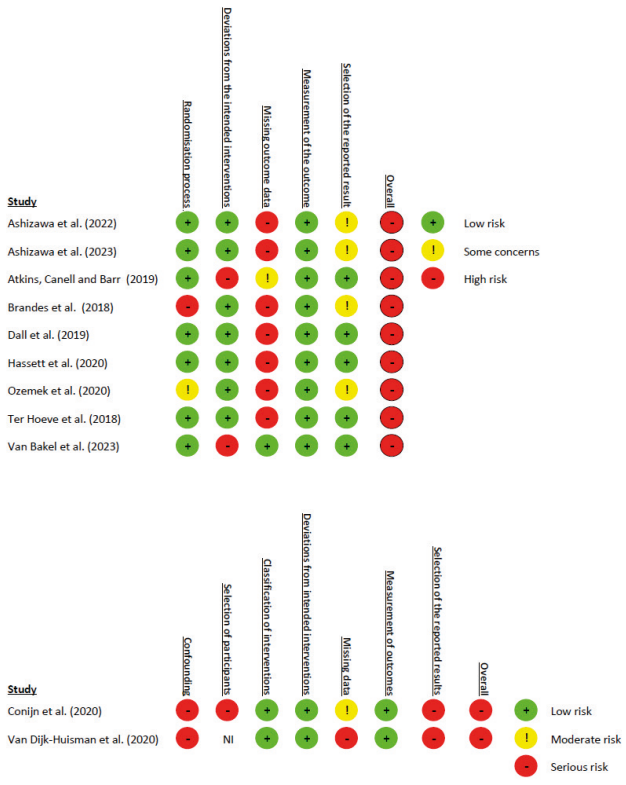

Figure 2. Quality assessments of the studies. a) RoB2 quality assessments, b) Robins-I quality Assessments
NI = No Information

Table 3. Sedentary outcomes

Feedback on	SB outcome measure	Unit	Author (year)	Estimate (95% CI) *Intervention minus control*	p value	Study conclusion
	Outcomes compared between intervention and control					
SB	Sedentary time	Hours/day	van Bakel et al. (2023)[35]	-0.4 h (-1.0, 0.3)	P=0.27	Although the intervention was feasible, there was no evidence of effectiveness of the intervention
	Number of prolonged sedentary bouts	Number/ day	van Bakel et al. (2023)[35]	-0.1 (-0.8, 0.5)	p=0.71	The number of prolonged sedentary bouts reduced, but change was comparable between groups.
SB & PA	Sedentary time	Percentage change	Ashizawa et al. (2022)[28]	-7.9%,	p=0.018	An approach that encourages SB reduction reduces SB more than an approach that promotes PA.
			Ashizawa et al. (2023)[27]	PI: -7.8% (-13.88, -1.65) FU: -6.8% (-12.67, -0.88)	PI: p=0.013 FU: p=0.025	Encouragement of reducing SB is effective up to 6 months after discharge
	Sitting time	Minutes/ day	Dall et al. (2019)[31] *	52 min (-118, 23)	p=0.54	There was no evidence of effectiveness of the intervention.
	Time spent in bed	Minutes/ day	Dall et al. (2019)[31] *	-70 min (-265, 125)	p=0.48	There was no evidence of effectiveness of the intervention.
	Sit-to-stand transitions	Number/ day	Hassett et al. (2020)[32]	3 weeks: 0 (-4, 3) 6 weeks: 2 (-2, 6)	3 weeks: p=0.88 6 weeks: p=0.31	There was no evidence of effectiveness of the intervention.

Table 3. Sedentary outcomes (continued)

Feedback on	SB outcome measure	Unit	Author (year)	Estimate (95% CI) *Intervention minus control*	p value	Study conclusion
PA	Sedentary time	Interaction effect	Conijn et al. (2020)[36] *	DH: (-1.57, 0.17) † AD: (-1.36, 1.00)	DH: p=0.11 AD: p=0.76	IG tend to (not significant) spend less time sedentary in hospital, not after discharge.
		Percentage change	Ter Hoeve et al. (2018)[34]	B=0.39 (0.82, 1.59)	p=0.53	There was no evidence of effectiveness of the intervention.
	Sedentary bouts ≥ 30 min	Percentage change	Ter Hoeve et al. (2018)[34]	B=0.76 (1.02, 2.53)	p=0.40	There was no evidence of effectiveness of the intervention.
	Time spent upright	Hours	Atkins, Canell and Barr (2019)[29] *	0.55 hrs.	p=0.004	Reading steps from pedometers increases the time spent upright in first week of rehabilitation.
	PA on POD1	Minutes	van Dijk - Huisman et al. (2020)[37] *	B 28.43 (5.55, 51.32) SE 11.50	p=0.016	The intervention shows potential to enhance PA levels and recovery process
	Outcomes compared pre-post within a group					
PA	Sedentary time	Percentage change	Ozemek et al. (2020)[33]	CG: 1.3% PF: 2.6% PF+MM: 1.8%	CG: p=0.29 PF: P= 0.03 PF+MM: p=0.19	CR programs are encouraged to implement PA feedback with individualized PA goals to support the increase in PA and potentially decrease SB.
		Minutes/ day		C: 14.6 min PF: 22.4 min PF + MM: 6.5 min	UC: p=0.34 PF: p=0.01 PF+MM: p=0.54	

Table 3. Sedentary outcomes (continued)

Feedback on	SB outcome measure	Unit	Author (year)	Estimate (95% CI) *Intervention minus control*	p value	Study conclusion
	Inactive time	Minutes	Brandes et al. (2018)[30]	Onset-1m IG: -10 min CG: -9.5 min Onset-6m IG: -54 min CG: -29.3 min	onset-1m IG: p>0.05 CG: p>0.05 onset-6m IG: p<0.05 CG: p>0.05	The intervention group significantly decreased the inactive time 6 months post rehabilitation compared to one month post rehabilitation.
	Mean duration of inactive bouts	Minutes	Brandes et al. (2018)[30]	Onset-1m IG: -1.2 min CG: 0 min Onset-6m IG: -2 min CG: -2.6 min	onset-1m IG: p>0.05 CG: p>0.05 onset-6m IG: p>0.05 CG: p>0.05	IG and CG both did not significantly reduce the mean duration of inactive bouts.
	Maximum duration of inactive bouts	Minutes	Brandes et al. (2018)[30]	Onset-1m IG: -17.4 min CG: -7.2 min onset-6m IG: -28.4 CG: -30.8	onset-1m IG: p>0.05 CG: p>0.05 onset-6m IG: p>0.05 CG: p>0.05	IG and CG both did not significantly reduce the maximum duration of inactive bouts.

*Study did not report on change over time, † study did not report effect estimate, only the 95% CI, SB = sedentary behavior, PA = physical activity, PI = post intervention, FU = follow-up, PA = physical activity, DH = during hospitalization, AD = after discharge SE = standard error, IG = intervention group, CG = control group, PF = pedometer feedback group, PF+MM = pedometer feedback + motivational messaging group, CR = cardiac rehabilitation, POD1 = post operative day 1, 1m = 1 month, 6m = 6 months

DISCUSSION

This review provides an overview of the effect of feedback from an objective measurement for older adults in geriatric rehabilitation on their sedentary behavior. Included studies varied greatly in both interventions (such as backgrounds of participants, the way feedback was provided and duration of the intervention) as in the follow-up, outcome measures and units that were reported. Besides, most studies were of poor quality. In six studies, the authors described a significant decrease in a sedentary behavior outcome[27-30, 33, 37]. The other five studies did not report a statistically significant difference[31, 32, 34-36]. Two of the eleven studies did not examine the preferred contrast of interest by conducting only within-group comparisons[30, 33]. None of the studies reported a harmful or negative effect of the intervention. Evidence for the effectiveness of an intervention providing feedback based on objective measurement to decrease sedentary behavior remains inconclusive.

The methods used in studies that described an effect on sedentary behavior varied as much as studies that did not report a significant effect. Not one component appeared to be the most successful. A suggestion in the literature to increase effectiveness of an intervention to change behavior is the incorporation of more behavior change techniques or the incorporation of feedback into a multi-component intervention[38]. However, the number of intervention components in this review varied but interventions with more components did not show higher effectiveness than studies with fewer components. Perhaps it is not the number of the components of interventions that is important, but rather their tailored use[39]. With over 90 possible behavior change techniques, the person delivering the intervention should be aware of the personal preferences of a patient, which can depend on a person's capabilities, the opportunities that are offered and the motivation to change[14, 15]. Studies in this review did not describe whether the interventions had taken these factors into account. The possible lack of a personalized approach may also explain why the frequency of the feedback and the form in which feedback was provided showed no effect on the outcome. Besides, the effectiveness of studies that incorporated the feedback as blended care, did not differ from the effectiveness of studies that provided feedback in addition to the care-pathway. This contrasts with the literature, which states that digital interventions in rehabilitation are more effective when provided as blended care[40]. In addition, the variation in outcomes could be explained by the difference in accelerometers that were used in the interventions.

All accelerometers measure sedentary behavior slightly differently, and the validity of accelerometers is known to vary, especially for individuals with a divergent movement pattern (i.e., smaller step length or low walking speed)[41, 42].

Studies in this review did not describe a harmful effect but were inconclusive regarding the effectiveness of feedback on reducing sedentary behavior in this target group. The studies that focused on sedentary behavior did not report a larger effect than studies with interventions focused on physical activity. This is in contrast to the literature, which suggests that interventions for adults with a focus on sedentary behavior instead of physical activity tend to have a more promising effect on decreasing sedentary behavior[43, 44]. The difference could be due to the geriatric rehabilitation target group in this study. Although patients had diverse backgrounds, they all received rehabilitation and were older individuals. However, despite the often-described barriers for older adults to use eHealth, such as low digital literacy, studies show that older patients can engage with eHealth during rehabilitation and that using eHealth can potentially improve rehabilitation outcomes[40, 45, 46]. Our inconclusive outcomes show similarities with those of other studies focusing on older adults. In community-dwelling older adults, interventions with a (digital) feedback component have the potential to reduce sedentary time, but did not achieve statistical significance[17]. According to the authors, the lack of statistical significance in this meta-analysis could be due to both the small number of included studies and the small sample size of existing studies. Studies in younger adults provide more evidence on reducing sedentary behavior by eHealth with a feedback component. For example, a scoping review reporting on the reduction of sedentary behavior with single component mHealth interventions in young and middle-aged adults reported a positive effect in seven of the nine studies[47]. A systematic review and meta-analysis on community-dwelling inactive young and middle-aged adults also provided evidence that mobile health interventions reduce sedentary behavior[48]. Overall, the literature tends to be mildly positive about the reduction of sedentary behavior but also states that much is unclear and that more high-quality studies are required.

Although all studies scored a high risk of bias on the quality assessment, the quality of the studies clearly varies. Four studies scored a high risk in only one domain, which resulted in an overall rated high-risk rating[31, 32, 34, 35]. However, they scored a low risk on the four other domains. These four studies all reported no effect of the intervention. Since all studies included in this review showed an overall high risk of bias, we can only speculate about the potential

effect in a high-quality study. In some cases, the quality of included studies may even seem higher than it actually is, because clarity of results is not a domain in the quality assessment. The lack of this domain in some cases resulted in, for example, a low-risk score on the domain *selection of the reported results*, while limited information on the exact selection of results was reported. Based on the available data, derived solely from studies of suboptimal quality, higher quality studies did not show a larger effect compared to lower quality studies.

Strengths and limitations

The extensive search strategy that covered five databases is the first strength of this systematic review. A second strength is the use of double-blind screening for study inclusion. A third strength is that this is the first review to report on the effectiveness of feedback on objectively measured sedentary behavior for older individuals in geriatric rehabilitation. Nonetheless, several limitations should also be noted. Part of the studies focused primarily on increasing physical activity rather than targeting sedentary behavior. This might have influenced their results on sedentary behavior. Second, the quantitative comparison across studies was hampered by the large variety in measurement methods and reported outcomes, complicating the synthesis of the results. Further, there was the heterogeneity in content, duration, and frequency of the administered interventions. Therefore, no meta-analyses could be conducted on this topic.

CONCLUSIONS

Although some studies with older individuals in geriatric rehabilitation indicate a reduction in sedentary behavior following interventions with objective feedback, the effects remain undetermined. Clear evidence is lacking as only a limited number of studies could be included in this review and almost half of the studies did not find a positive effect on sedentary behavior. All included studies had a high risk of bias. Additionally, some studies did not report on the change over time or only conducted within-group comparisons. Remarkably, no indications regarding which type, duration or content of the interventions would be most optimal to affect the outcome regarding sedentary behavior could be found. To optimize rehabilitation for older people, high-quality randomized controlled trials are essential. Future research should focus on gaining insight into (1) the best method for providing feedback on sedentary

behavior, and (2) the decrease in the total volume and bouts of sedentary behavior required to achieve clinical relevance.

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Declaration of conflicting interest

The authors declare no conflict of interest.

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Ethical considerations

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

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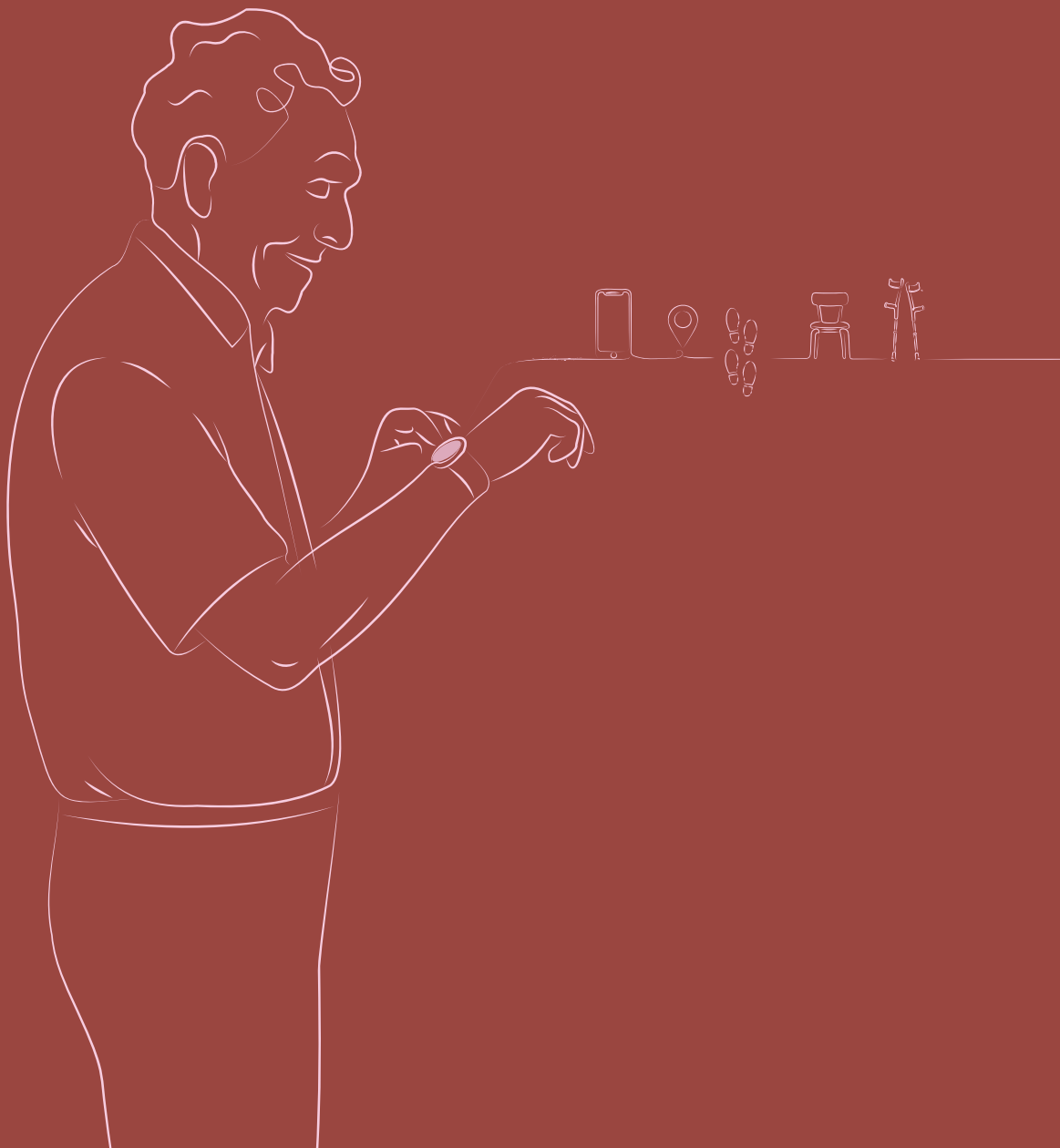
SUPPLEMENTAL MATERIAL

Link to supplemental material

QR code to supplemental material



Chapter 5

Usability and feasibility of a wearable sensor providing feedback on sedentary behaviour during inpatient and home-based geriatric rehabilitation

Suzanne Debeij
Miriam Haaksma
Margot de Waal
Jolanda van Haastregt
Margriet Pol
Marise Kasteleyn
Eléonore van Dam van Isselt

Submitted

KEY SUMMARY POINTS

Aim: To explore the usability and feasibility of a sensor-based monitoring system that provides feedback on sedentary behaviour during inpatient and home-based geriatric rehabilitation from the perspectives of patients and healthcare professionals.

Findings: Usability was perceived as limited due to various concerns, e.g. measurement accuracy. Feasibility was deemed sufficient but requires practical improvements.

Message: Sensor-based feedback on sedentary behaviour in geriatric rehabilitation should be easy to use, accurate, aligned with patient goals, and supported by the entire multidisciplinary team to ensure usability and feasibility.

ABSTRACT

Objective: This study explored the usability and feasibility of a sensor-based monitoring system that provides feedback on sedentary behaviour during inpatient and home-based geriatric rehabilitation from the perspectives of patients and healthcare professionals. Additionally, we examined care professionals' preferences for a multicomponent intervention and patients' activity levels and patterns.

Methods: This mixed-methods study, which is part of the Better@Home study, included a focus group with care professionals and patient surveys to explore usability and feasibility of the sensor system. Activity data (e.g., sedentary time and bout duration) were collected via a wearable sensor monitoring system. Focus group data were analysed using the framework method; other data were analysed descriptively.

Results: Twenty-six patients and nine care professionals participated. Usability was perceived as limited due to various concerns, e.g. measurement accuracy. Adherence levels were high, and feasibility was deemed sufficient but requiring practical improvements. Patients were sedentary over 90% of the day during both inpatient and home-based rehabilitation.

Conclusions: This study showed sufficient feasibility and limited usability of a sensor-based monitoring system in geriatric rehabilitation that provides feedback on sedentary behaviour. To ensure contextual fit and usability, a pre-implementation analysis is recommended. The system should be easy to use, accurate, aligned with patient goals, and supported by the entire multidisciplinary team.

Key words: *eHealth, digital health technologies, post-acute care, elderly, wearable, feedback*

INTRODUCTION

Geriatric rehabilitation plays a critical role in helping older individuals with disabling impairments to regain independence[1]. It improves various outcomes, including functional parameters, and reduces nursing home admissions and mortality[1]. It can be delivered in an inpatient setting, home-based, or through a combination of both, with home-based rehabilitation often serving as a transitional phase[1, 2]. Treatment programs are personalized and consist of several modules of geriatric rehabilitation.

One of the core elements in rehabilitation is engaging in physical activity to regain functional performance. However, recent studies indicate that patients in geriatric rehabilitation are highly sedentary[3, 4]. Sedentary behaviour is defined as "any waking behaviour resulting in an energy expenditure of ≤ 1.5 Metabolic Equivalent of Task while in a sitting, reclining or lying posture"[5]. The high level of sedentary time persists throughout the rehabilitation and afterwards[3, 6]. This is concerning, because prolonged sedentary behaviour is associated with an increased risk of various non-communicable diseases and all-cause mortality, even when older adults meet the recommended PA guidelines[7, 8]. Both excessive total sedentary time and prolonged, uninterrupted sedentary bouts contribute to these health risks[9]. Increasing the number of breaks in sedentary time and decreasing total sedentary time may be a more feasible starting point for vulnerable groups than increasing physical activity[10]. The lower physical demand might be a gateway to more activity. Nevertheless, the optimal approach to reducing sedentary behaviour in geriatric rehabilitation remains unclear.

Monitoring and feedback are behaviour change techniques that may help older individuals reduce and change their sedentary behaviour[11-14]. *Monitoring* involves observing a person's behaviour, and *feedback* entails receiving an evaluative response based on the observed behaviour[14]. Feedback and monitoring can facilitate behaviour change by providing insight into one's current behaviour compared to the norm or into oneself, supporting goalsetting, enhancing motivation and strengthening self-efficacy[15]. Wearables that measure physical activity, such as the Hipper, can support monitoring and provide feedback[16, 17]. In the Netherlands the Hipper is already being used in geriatric rehabilitation, offering insight into daily physical activity. When combined with therapeutic coaching, it has demonstrated positive effects on

perceived daily functioning[16]. It could be useful to investigate its potential for monitoring and adapting sedentary behaviour.

Assessment of users' perspectives on usability elements, such as ease of use, added value and user satisfaction, and on feasibility aspects, including practical integration into existing workflows, logistics, and adherence, is important for the success of eHealth interventions in geriatric rehabilitation[18]. Therefore, the primary aim of this study is to explore the usability and feasibility of a sensor monitoring system that provides feedback on sedentary behaviour during both inpatient and home-based geriatric rehabilitation from the perspectives of patients and healthcare professionals. Furthermore, the study aims to gain insight into patients' activity patterns during rehabilitation, and to explore care professionals' preferences regarding the content of a multi-component intervention to reduce sedentary behaviour.

METHODS

Study design and participants

This study is embedded in a multicentre cohort study, named Better@Home (see Figure 1), which included 110 patients across eight geriatric rehabilitation centres[19]. Its main objective study was to "*assess the outcomes, costs and feasibility of home-based GR after shorter inpatient rehabilitation*"[19]. Participants were included during inpatient rehabilitation, with a home-based follow-up. The current mixed-methods sensor study was conducted at one of the geriatric rehabilitation centres participating in Better@Home, and patients followed their treatment program.

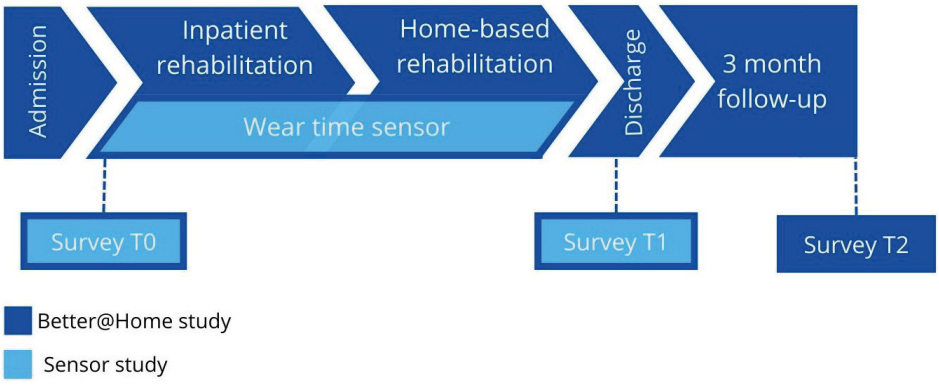


Figure 1. Patient journey in the Better@Home study and in this sensor study

All participants for this sensor study were recruited from a geriatric rehabilitation centre located in an urban area in the Netherlands offering inpatient and home-based rehabilitation. Patients and their care professionals were invited to participate. The aim was to include a minimum of 15 patients. Patients were eligible to participate if they: 1) were admitted to the rehabilitation centre between December 2023 and November 2024; 2) were considered eligible for participation in the Better@Home program study as assessed by each facility's multidisciplinary team based on patients' physical, cognitive, and psychological functioning; 3) lived in the community; 4) were able to speak and understand Dutch; 5) were able to provide informed consent (see the Better@Home protocol for a more detailed description)[19]. The multidisciplinary team determined whether the participant was eligible for using the sensor monitoring system. Care professionals were eligible for participation if they 1) participated in the Better@Home study, and 2) were involved in the treatment of the patients who used the sensor during the data collection. These professionals included occupational therapists and physical therapists.

The Medical Ethics Committee of University Hospital Maastricht/Maastricht University determined that the study was not subject to the Dutch Medical Research Involving Human Subjects Act (WMO) (reference number 2023-3744).

Sensor monitoring system

The Hipper sensor monitoring system (Hipper Therapeutics B.V.) was used to assess patients' movement behaviour[17]. The system consists of multiple components: the sensor (PAM AM400, 3-dimensional accelerometer sampling at 12.5Hz) that provides output every minute, a wireless transmitter, the web-page dashboard for patients, and the web-page dashboard for care professionals. The sensor is worn on the hip and collects data that is transferred wirelessly to the dashboards for care professionals and patients. Only the dashboards require an internet connection to function. As part of the monitoring system, care professionals coach patients on their movement behaviour based on the data collected by the sensor[16]. The sensor monitoring system (including the coaching by care professionals) will hereinafter be referred to as "sensor" or “sensor system”.

Three different sensors were used during this study: type 1, type 2.1, and the revised version, type 2.2. A previous version of the sensor (type 1) was already implemented in the rehabilitation centre. Before the start of our study, type 1

was adapted into a new prototype (type 2.1). At the start of our study, we used the type 2.1 sensor, which provided an output per minute instead of 15 minutes as type 1 did. The increased output led to the redesign of the professional and patient dashboards. The data were presented on the dashboard as Physical Activity Measure (PAM) scores per minute. The type 2.1 sensor was evaluated for reliability. However, during a required update to its algorithm, we used the type 1 version. After the update we switched to type 2.2.

Procedure

Before the start of data collection, all care professionals involved with the sensor system underwent a refresher training on its utilization, which included coaching and a presentation by a researcher (SD) and the company providing the sensor system. Additionally, the training aimed to increase care professionals' knowledge about the risks of sedentary behaviour and explained the differences between the previously used sensor (type 1) and the sensor to be used in the study (type 2.1).

Data collection took place between January 2024 and January 2025. Patients who participated in this study followed their treatment program as determined by the rehabilitation team (following Better@Home protocol)[19]. Care professionals approached eligible patients within two weeks of admittance to rehabilitation and informed them about the study with a verbal explanation and an information letter. After signing the informed consent form, participants received a sensor system, an explanation regarding the reason for wearing the sensor, and an explanation of its application. The participants were advised to clip the sensor to their belt while dressing in the morning and were informed that they were not required to wear the sensor at night nor during showering, bathing, or swimming. Patients wore the sensor during both inpatient and home-based rehabilitation.

The project team of the participating geriatric rehabilitation centre gathered every six weeks to discuss the sensor and its application, so any arising issues could be addressed quickly.

Data collection

We used three types of data collection: 1) a focus group with care professionals towards the end of the data collection to assess their perspective on the usability and feasibility of the intervention, as well as their preferences for a multicomponent intervention; (2) interviewer-administered surveys among

patients at admission (T0) and after discharge (T1) from rehabilitation to assess their perspective on usability and feasibility of the sensor system; and (3) quantitative data derived from the sensor (PAM scores per minute) to obtain insight into patients' activity patterns.

Usability and feasibility from a care professional perspective

Two researchers (one female, one male (SD, MZ)) guided the focus group. Both researchers had experience conducting focus groups and had met some of the participants prior to the focus group. The User Experience Honeycomb model was used to formulate the focus groups questions[20, 21]. The focus group was divided into small group discussions and a plenary discussion. For the small group discussions, participants were divided into two groups to discuss and respond to four statements that were written on posters: 1) *What keywords come to mind when you think about your experience with the sensor system;* 2) *I would use the sensor system more often if…;* 3) *What are the benefits of the sensor system in its current version for (a) you and (b) patients;* 4) *If an intervention is to be implemented to reduce sedentary behaviour in geriatric rehabilitation, the following must be considered…*

In the plenary discussion follow-up questions, relating to usability and to feasibility, were posed: *Is the current version of the sensor system useful for you as a care professional?* and *Is using the current version of the sensor system feasible for you as a care professional?* Please refer to supplementary material 1 for the topic list. The interviewer made notes during the focus group. The plenary discussion was audio-recorded, and the recordings and digitized posters were stored in a secure and restricted data folder.

Usability and feasibility from a patient perspective

Two interviewer-administered surveys were used for each patient: one at the start of the rehabilitation (T0) and one at the end (T1) (see Figure 1.). At T0, the patient's characteristics were collected, and the Barthel Index was administered. The T1 survey consisted primarily of closed-ended questions related to feasibility and usability based on the User Experience Honeycomb[20, 21]. An example question regarding feasibility is '*Have you received adequate support from your care professionals in using the sensor system?'.* One of the usability questions was '*To what extent did using the sensor system have added value for you?'.* Scoring options differed per answer. See supplementary material 2 for a list of questions and answer options related to the sensor

system and its application. Reponses were recorded in Castor EDC. In addition, sensor wear time was used to assess adherence as part of feasibility.

Sensor data

Activity patterns, recorded as minute-by-minute activity data, were retrieved from the sensor worn by the patients, and then summarized as described in Box 1. For the data to be included in the analysis, the sensor had to be worn for a period of at least four days. This applies to both the inpatient phase and the home-based phase. The activity data from the sensor system was obtained as a PAM score per minute.

Box 1. Types of movement variables

Variable	Description
Sedentary time	Waking time (with a minimal duration of one minute) spent on activities characterized by an energy expenditure below or equal to 1.5 MET[5].
Light physical activity (LPA)	Time (with a minimal duration of one minute) spent on light physical activity characterized by an energy expenditure between 1.5 MET and 3.0 MET
Moderate to vigorous physical activity (MVPA)	Time (with a minimal duration of one minute) spent on moderate to vigorous physical activities characterized by an energy expenditure above or equal to 3.0 MET.
Prolonged sedentary bout duration	Time spent in an uninterrupted period of sedentary behaviour[22], with a minimal length of 30 minutes.
Half-life bout duration (W50%)	A weighted median bout duration in which the sedentary bout duration above and below half of all sedentary time is accumulated[23, 24].

Analysis

Usability and feasibility from a care professional perspective

The focus group's transcript was coded and analysed according to the Framework method principles[25]. The analysis was used to identify key elements and common themes regarding usability, feasibility, and preferences for a multicomponent intervention. Following the Framework method, the audio recording was first transcribed (by SD) and pseudonymized. Transcripts were not provided to participants. SD then familiarized herself with the data by checking the transcripts. Two researchers (SD, MH) performed the initial inductive coding of the transcript. SD and MH then compared and discussed their coding in a consensus meeting. Discrepancies were resolved through

discussion, and the codebook was refined accordingly. SD applied the refined codebook to the focus group and notes on posters in Atlas.ti 23. The data was summarized in a matrix and illustrated with quotations. Finally, the data was interpreted, and the findings were discussed with the rehabilitation centre project team.

Usability and feasibility from a patient perspective

Descriptive statistics were used to examine the characteristics of study participants and to analyse survey data responses. Data was not normally distributed and was therefore summarized as medians and interquartile ranges. Categorical data is presented as percentages. Open-ended responses were grouped and summarized.

Sensor data

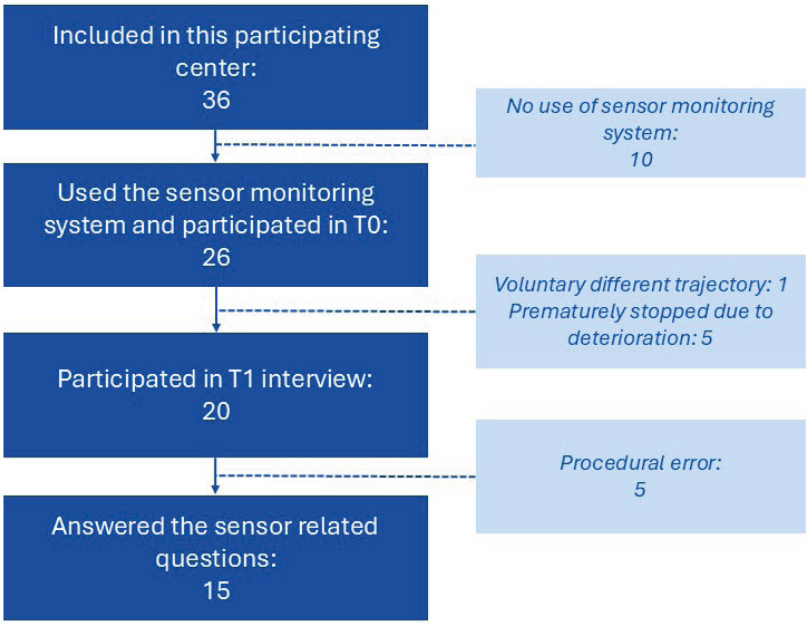
Only data marked as *awake (*defined as data collected between the first and last registered movement during a day) and from days marked as *valid* (PAM day score >1) were included in the analysis. Data from the first and last days of measurement were excluded due to incompleteness. Adherence was calculated by dividing the number of days with a PAM day score exceeding 1, by the total number of days recorded by the sensor system. The movement variables (Box 1) were averaged per person and stratified by rehabilitation phase (inpatient vs. home-based). Data was pooled, and outcomes were analysed descriptively, reported as medians and interquartile ranges (IQR). Statistical analyses were performed using IBM SPSS statistics version 29.

RESULTS

Baseline characteristics

The Better@Home study included 36 patients from the participating geriatric rehabilitation centre. The multidisciplinary team determined that eight patients were not eligible to use the sensor system. For two patients no sensor system was available. So, in this sensor study, 26 patients were included. Twenty patients participated in the T1 interviewer-administered survey (see Figure 2). Due to a procedural error during data collection, only 15 patients answered the sensor-related survey questions.

Figure 2. Flowchart showing the number of participants during the study



The median age of the patients was 77 years (IQR 70.5-84.3), 16 patients were female (61.5%) and 18 patients lived independently and alone (69.2%). Almost 35% of patients were in the rehabilitation centre due to elective orthopedy/ trauma. The second most common diagnosis was respiratory disease (23.1%). Patients spent a median of 25.5 days (IQR 19.0-45.0) in inpatient rehabilitation and 46.5 days (IQR 34.0-78.0) at home during their treatment. Further details are included in Table 1. Of the nine participating care professionals, seven (77.8%) were physical therapists and two were occupational therapists. Seven of the participating care professionals (77.8%) were female.

Table 1. Characteristics of participating patients (N=26)

Median (IQR) age in years	77 (70.5-84.3)
Female (N (%))	16 (61.5)
Living situation (N (%))	
Independent, alone	18 (69.2)
Independent, with other persons	8 (30.8)
Diagnosis (N, (%))	
Elective orthopedy/trauma	9 (34.6)
Respiratory diseases	6 (23.1)
Stroke	5 (19.2)
Oncological diseases	2 (7.7)
Amputations	1 (3.8)
Falling and kidney insufficiency	1 (3.8)
Intestinal surgery	1 (3.8)
Rib fracture	1 (3.8)
Barthel Index (N, (%))	
Total dependency	4 (15.4)
Severe dependency	4 (15.4)
Moderate dependency	13 (50.0)
Slight dependency	5 (19.2)
Median length of stay in days (IQR)	
Inpatient (n=26)	25.5 (19.0-40.5)
Home-based (n=24)	46.5 (34.0-78.0)
Inpatient + home-based (n=24)	84.5 (57.3-107.3)

Usability and feasibility from a care professional perspective

Three major themes emerged from the focus group regarding the primary objective, i.e., the purpose of using the sensor system, experiences with using the sensor system, and consequences of the experiences. For the secondary objective regarding preferences for a multicomponent intervention, the following themes emerged: the preferences, roles in using the sensor, and the importance of the rehabilitation climate.

Regarding the application of the sensor, care professionals indicated that the purpose of using the sensor system was to discuss and map a patient's load and capacity balance. They considered its use to be successful only when it provided a patient insight into their own activity and when patients changed their

behaviour accordingly, especially when they needed extra support to change their activity. The care professionals found the sensor system to be a useful conversation starter, enabling meaningful and motivational conversations. They indicated that it provided insight into patients' activity patterns and intensity, both for them and their patients. As one professional said:

"*You can see, at least with the old sensor [type 1], when someone has moved. And the intensity of that movement. And you can also see if someone practices all morning and does nothing in the afternoon – which is what you don't want – or when someone becomes inactive after six o'clock." (D1, physical therapist)*

On the other hand, professionals noted that the PAM score was a source of unclarity. As one of them stated:

"The PAM [physical activity measure] score is unclear; a patient doesn't understand what 3, 4 or 20 means." (D3, occupational therapist)

Other experiences that decreased the usability of the sensor system were using it without a clear patient treatment goal and the perceived inaccuracy of the measurements. Despite the sensor being updated during the study, care professionals still felt like the data from the sensor system had low credibility. One provided a clear example:

"I actually had a patient where I said 'Ah, you didn't take the stairs, because look, it only shows this…' She was really offended, because she had been working very hard… the sensor system just hadn't recorded anything." (D7, physiotherapist)

Furthermore, due to the increase in datapoints, the graphs belonging to sensor types 2.1 and 2.2 were perceived as more complex and less interpretable than those from sensor type 1. This resulted in feelings of frustration among some professionals. The care professionals considered the dashboard to be accessible for patients with basic digital skills, but they also thought that patients often do not have these skills. The different steps necessary to access the dashboard also reduced its feasibility. Professionals furthermore felt that technology like this sensor system will be important in future rehabilitation. However, the feasibility of the sensor system was also reduced by practical complications, including the risk of device loss, logistical issues, and the number of steps required to include a patient in the system and transfer the patient to the home-based setting.

Care professionals' preferences for a multi-component intervention

When the care professionals were asked about the desired components of an intervention to decrease sedentary behaviour, they emphasized that an intervention should be easy to use, have a clear objective, and should incorporate technology. They highlighted the importance of increasing patients' and informal caregivers' knowledge about sedentary behaviour, emphasizing that the technology should motivate patients to engage in physical activity. Furthermore, they wanted a pre-implementation analysis of the technology to be used (e.g., what do we need, how do we want to use it, and which technology is available). Ideally, the technology should provide direct visual or tactile feedback and offer insight into patterns, intensity, and type of activity. They noted:

"... insight into when someone is active and for how long (D3, occupational therapist)
... and the type of activity, that would be good too (D6, physiotherapist)
... and at what time during the day (D9, physiotherapist)
... and the development over time." (D2, physiotherapist)

Care professionals identified the general rehabilitation climate as highly important; the culture should invite being physically active, be safe to move around in, and care professionals should act as role models. They also described several preconditions for a multicomponent intervention. First and foremost, the entire rehabilitation team should be involved in the intervention.

Usability and feasibility from a patient perspective

Fifteen patients answered the survey questions regarding the usability and feasibility of the sensor. Twelve of them stated that their care professional asked them if they wanted to use the sensor. One patient reported that the question was not asked, and two could not recall whether it was asked. Thirteen patients reported using the sensor during both the inpatient and home-based rehabilitation, indicating a high level of adherence. However, the use and usability of the sensor were not clear to all users. Four patients thought the purpose of the sensor was to change their level or awareness of activity. Three other patients thought the purpose was so the care professionals could monitor their behaviour. In addition, responses on why it was used included: "*for research*", "*I didn't think about that*" and ‘"*I don't know, I'm in a wheelchair*". Regarding the trustworthiness of the sensor, even patients said they (partially) trusted it, while the others did not.

Eight patients, slightly more than half, reported the sensor was easy to use. Thirteen patients indicated that using the sensor offered no added value or advantages. One reported it had some value, and another noted that the sensor facilitated external accountability for exercise adherence. Seven participants did not experience any disadvantages from using the sensor. Among the patients who did, one in five indicated that the sensor kept coming off. Other disadvantages included forgetting the sensor, easily losing it, or breaking it. Patients did not mention the dashboard. Despite the disadvantages, five patients said that they would recommend the sensor, and four were undecided. The remaining six patients would not recommend it.

Regarding the support patients experienced with using the sensor, almost half, i.e. seven patients, reported that the care professionals did not provide adequate support. Three patients indicated that they would have preferred to review the results together with the care professional during therapy, and two expressed a desire for more information about the sensor and its use. Only one patient was guided by an informal caregiver in using the sensor.

Sensor data

Sensor data from the 26 patients who used a sensor showed that 16 participants used it during both inpatient and home-based rehabilitation. Twenty-three patients used the sensor during inpatient rehabilitation. These 23 patients had a median use of 11.0 days (IQR 7.0 – 22.0), which corresponds to a median use of 100% (IQR 73.3 – 100.0) of the days the sensor was offered. During home-based rehabilitation, 19 patients used the sensor. The sensor was offered to them for a longer period (median: 34.0 days [IQR 25.0-45.0]). Patients used the sensor on 96.6% (94.1-100.0) of those days.

Activity pattern and intensity

During the inpatient rehabilitation, patients spent an average of 93.0% (IQR 81.2 – 97.3), or 665.8 (IQR 599.5-743.6) minutes of their waking day in sedentary behaviour. During home-based rehabilitation, this was 90.5% (IQR 79.9 – 97.7) . However, as total daily wear time increased in the home setting, the average absolute time spent in sedentary behaviour increased to 704.2 (IQR 600.4 – 896.4) minutes during home-based rehabilitation. The percentage of time spent engaged in MVPA was in both periods 0.0 (IQR 0.0 – 0.2). The percentage of time spent engaged in LPA was 6.9% (IQR 2.4 – 18.7) in the inpatient setting and increased by 14.1 minutes (2.6%) in the home-based setting.

The pattern and duration of sedentary bouts also showed differences between the inpatient period and the home-based period. The number of bouts was 37.9 (IQR 20.4 – 58.6) inpatient and 55.5 (IQR 37.4 – 78.8) home-based. The median bout length inpatient was 22.7 (IQR 10.0—34.3) minutes and home-based 14.9 (IQR 9.4 – 20.3) minutes. The time spent in bouts longer than 60 minutes decreased by 47.9 minutes (10.6%). More detailed outcomes are presented in Table 2 and supplementary material 3.

Table 2. Activity pattern and intensity during rehabilitation

	Inpatient *N=23*	**Home-based** *N=19*
Movement variables	**Median (IQR) per day**	**Median (IQR) per day**
Minutes wear time	730.0 (648.8 - 844.8)	796.6 (707.8 - 959.0)
% Spent in SB	93.0 (81.2 - 97.3)	90.5 (79.9 - 97.7)
% Spent in LPA	6.9 (2.4 - 18.7)	9.5 (2.3 - 19.8)
% Spent in MVPA	0.0 (0.0 - 0.2)	0.0 (0.0 - 0.2)
PAM score	5.8 (3.7 - 11.0)	8.8 (5.3-14.9)
Sedentary bouts*	***Inpatient*** *N=19*	***Home-based*** *N=14*
Number of bouts	37.9 (20.4 – 58.6)	55.5 (37.5-78.8)
% Spent in bouts 31-60 minutes	16.2 (10.6-20.3)	17.7 (11.4-21.9)
% Spent in bouts >60 minutes	42.4 (29.2-67.1)	31.8 (18.7-40.4)
Bout length in minutes	22.7 (10.0 – 34.3)	14.9 (9.4 – 20.3)
half-life bout duration	24.0 (6.0 - 77.0)	30.0 (19.0 – 46.3)

*Bout outcomes are derived only from sensors that measured every minute, while some patients wore sensors that measured every 15 minutes. This is why the sample size for these outcomes is slightly smaller.
SB = Sedentary Behaviour, LPA = Light Physical Activity, MVPA = Moderate to Vigorous Physical Activity

DISCUSSION

This study explored the perspectives of care professionals and patients on the usability and feasibility of a sensor system tracking sedentary behaviour during inpatient and home-based geriatric rehabilitation. The system was found to be easy to use, support motivational conversations, and provide insight into patients' activity levels and patterns. Yet its overall perceived usability was limited due to concerns regarding measurement accuracy, a lack of clear goals

for patients, and a lack of added value to the rehabilitation process perceived by both patients and professionals. While high adherence indicates promising feasibility, challenges such as experiences of limited support and logistical constraints, reduce the feasibility level to reasonable. According to the sensor data, patients exhibited sedentary behaviour more than 90% of their time, with light physical activity recorded between seven and ten percent of the time. Care professionals emphasized that a multicomponent intervention to decrease sedentary behaviour should be easy to use, include technology that provides feedback and motivates patients, involve the whole team, and offer a challenging rehabilitation environment.

While care professionals found the sensor to be a useful motivational conversation starter that provided insight into a patient's activity pattern, participants also identified several factors that limited its usability. The issues with measurement accuracy, tailored use, and added value correspond with existing literature[26-29]. Belief in the added value – also called performance expectancy[29] - is one of the key predictors for professionals and older individuals accepting an eHealth intervention[26, 30]. Some studies even suggest that high performance expectancy can overrule other implementation challenges[26]. Given the usability concerns raised by patients, future studies with eHealth in geriatric rehabilitation should address and enhance performance expectancy. Strategies may include educating professionals or training eHealth advocates to support successful implementation of usable eHealth[26].

Furthermore, our findings on feasibility are consistent with a systematic review on the use of eHealth in geriatric rehabilitation that stated that eHealth interventions in this setting show high adherence and can be feasible[31]. To optimize the feasibility and ensure it is used as originally intended, it is essential to provide adequate assistance and training for both patients and care professionals[27, 32-35]. This support is particularly important in populations that have more problems with accessing, using, and understanding eHealth, such as older adults [33]. To assist both care professionals and patients, the support system, in addition to providing technological assistance, should offer comprehensive support[34].

The sedentary time and LPA of patients in this study collected by the sensor, fall within the expected range when compared to other older patient populations (although definitions in literature vary)[3, 36-39]. For instance, during inpatient treatment, sedentary time of patients can range from 650 to over a thousand

minutes per day[36, 39, 40]. Studies show that this high level of sedentary time remains relatively stable throughout the inpatient rehabilitation[3, 40]. This is concerning, as reduced sedentary time and more frequent breaks are associated with lower levels of physical dependency and higher functional recovery[36, 41]. On the other hand, other studies also indicate that the sedentary time of patients following the transition to a home-based care program seems to decrease naturally, by up to 45 minutes[39, 42]. This may explain the observed relative decrease in sedentary time between the two settings in the present study.

When asked about their preferences for a multicomponent intervention to optimize reducing sedentary time, the care professionals stated that they would prefer an intervention with a clearly defined objective that utilizes technology such as sensors. As noted in the scoping review by Petrusevski et al. (2021), such interventions can be feasible for community-dwelling older adults and have the potential to reduce sedentary time by 24 to 130 minutes per day[43]. This can be a good starting point for the geriatric rehabilitation setting as well. Successful interventions included educational components and frequently incorporated self-monitoring and health coaching[43]. These are also components the professionals in this study would like to see in a future intervention. Also, the professionals' wish for a pre-implementation analysis aligns with literature that emphasizes the importance of assessing: 1) the current situation, including existing structures, processes, challenges and needs; 2) values associated with the intervention; and 3) stakeholders' perspectives. These assessments are necessary to overcome usability and feasibility issues[33, 44]. Moreover, the literature emphasizes that successful integration requires incorporating the role of the users into the organizational structure and processes, ensuring that technology aligns with these structures and processes, and deploying professionals in ways that support the intended outcomes of care[45]. Lastly, the need for a physically and culturally challenging rehabilitation environment to optimize outcomes, as indicated by professionals in our study, aligns with literature on this topic[46]. Taken together and supported by a broad analysis upfront, these different components could lead to improved usability and feasibility for care professionals.

Strengths and limitations

The different research methods used in this study provided broad insight into the usability and feasibility of the sensor, highlighting its notable strength.

Another strength is that we included the perspective of end-users of the sensor in both inpatient and home-based settings.

The study also had some limitations. First, the different versions of the sensor used during the study, some of which may have shown inaccuracies, resulted in the absence of minute data for some patients. Nevertheless, the results still paint a general picture of patients' activity levels and patterns during inpatient and home-based geriatric rehabilitation. Second, although the usability and feasibility questions were not validated and not all included patients were interviewed at T1, the responses provide a meaningful description of the topic. Additionally, the results raised questions about whether coaching was carried out properly for all patients. Finally, the study was conducted in just one rehabilitation centre, with only physical therapists and occupational therapists participating in the focus group. This may reduce the generalizability of the results.

CONCLUSION

This study has demonstrated reasonable feasibility and limited usability of a sensor monitoring system in geriatric rehabilitation that provides feedback on sedentary behaviour. The primary concerns included measurement accuracy, a lack of clear goals for the patient, the lack of added value, and practical considerations. On the other hand, a sensor monitoring system in geriatric rehabilitation can be feasible and a valuable tool to facilitate motivational conversations. To ensure the contextual fit and usability of a sensor monitoring system in rehabilitation, a pre-implementation analysis is necessary. The system should be user-friendly, accurate, aligned with patient goals, and supported by the entire, multidisciplinary team. Furthermore, user support is required for both care professionals and patients. These findings underline the importance of designing eHealth for geriatric rehabilitation that is not only functional, but also responsive to the needs of both patients and professionals, thereby ensuring that reducing sedentary behaviour becomes a shared and achievable goal.

STATEMENTS AND DECLARATIONS

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Competing interests

All authors declare that they have no competing interests. Hipper Therapeutics B.V. was not involved in the execution, analysis, or reporting of the study.

Compliance with Ethical Standards

The study was declared to be outside the scope of the Dutch Medical Research Involving Human Subjects Act (WMO) by the Medical Ethics Committee of University Hospital Maastricht/Maastricht University (reference number 2023-3744). All participants provided informed consent prior to their participation.

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Author contributions

Suzanne M Debeij: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, software, visualization, writing – original draft. Miriam L Haaksma: conceptualization, methodology, supervision, validation, writing – review & editing. Margot WM de Waal: conceptualization, resources, software, writing – review and editing. Jolanda CM van Haastregt: funding acquisition, writing – review & editing. Margriet C Pol: funding Acquisition, writing – review & editing. Marise J Kasteleyn: validation, writing – review & editing. Eléonore van Dam van Isselt: conceptualization, funding acquisition, methodology, supervision, validation, writing – review & editing.

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SUPPLEMENTARY MATERIAL 1. TOPIC LIST FOCUS GROUP

Roughly translated from Dutch to English

Introduction

"Good afternoon, very nice that you are all available today to talk to each other about the use of the sensor. For those who don't know me, my name is SD and I am a PhD candidate. I don't work for the company of the sensor monitoring system. I am researching the use of eHealth in geriatric rehabilitation and will lead the focus group today. There is MD, who is the second in this focus group today.

In the past year you have used the sensor monitoring system. The difference with the years before was that it was used with more patients, and the sensor monitoring system itself was a little different than before. Today I am curious about your experience with this and your ideas for improvement.

We'll start with a round of introductions. Then you will split up into groups to different posters. Each poster contains a question or a statement. It is up to you to write down your opinion about this on the posters. After about 5 minutes I indicate that there is still some time to finish. When the time is up and you go with your group to the next poster, until you have been to all of them. Then we all come together to discuss together what has come forward and why it has come forward.

The presentation and discussion of the posters together will be recorded. In the analysis, your data is anonymized, and the material is not shared outside the research team, so you are completely anonymous in the analysis.

I will start the recording in a moment and ask one of your representatives if it is okay if the conversation is recorded. Are there people who don't like it?"

-Start recording-

"Do you agree that the conversation is recorded?"

Introduction (5-10 minutes)

I would like to ask you all to introduce yourselves. Would you like to indicate the following?

- Name
- Role within the organization
- Familiarity with the sensor monitoring system prior to the study

Thank you. Now let's move on to the posters. You can divide into groups at the posters, make sure the groups are approximately the same size. It doesn't matter which poster you start with, you will get to all of them.

Core (± 7 minutes per poster (based on 4 posters)) (±40 minutes total)

Poster 1: What keywords come to mind when you think about your experience with the sensor system?

Any further questions for discussion:

- Why?
- Is the information within the dashboard easy to find?
- What do you think of the simplicity of use?
- Is it accessible to patients?

Poster 2: I would use the sensor monitoring system more often if...

Any further questions for discussion:

- Is it feasible for you as a professional to use the current version of the sensor monitoring system?
- And for patients?
- Statement: I (sometimes) prefer not to use the sensor monitoring system because..? (What are barriers?)
- What prevents you from using the sensor?
- Why not use the sensor?
- *What are the impeding factors and the facilitating factors for the deployment of the sensor?*
  - Can the sensor be trusted and believed?

Poster 3: What are the benefits of the sensor system in its current version for (a) you and (b) patients?

Any further questions for discussion:

- When is it successful for you?
- What would you like to get out of the use of the sensor?/ What would you like to use the sensor for?
- Why would you use the sensor, what could the sensor do for patients, informal caregivers and professionals?
- Is the current version of sensor useful for you as a professional?
- And for patients?
- What are the main advantages of using the sensor?

- *What are the impeding factors and the facilitating factors for the deployment of the sensor?*

Poster 4: If an intervention is to be implemented to reduce sedentary behavior in geriatric rehabilitation, the following must be considered…

- What kind of aspects should an intervention consist of?
- Who are important to include in a broad intervention?
- Who will work with it in practice?
- Does the sensor fit these needs and interests? Why?

Closing (5-10 minutes)

"Thank you for your input We have arrived at the conclusion of the focus group. I have some final questions."

- What do you think are the most important points we discussed today?
- Is there anything else that you feel has not been discussed and that could be important for the research?
- Would you like to share something else?

"If you think of something later that you want to share, you can contact me by email ([mail]) or telephone ([phone number]). We would like to thank you very much for your participation in this focus group."

"Have a nice evening"

SUPPLEMENTARY MATERIAL 2. QUESTIONS IN THE SURVEY RELATING TO THE USE OF THE SENSOR

Question	Answer options*	Related to
Questions about the use of eHealth		
Have your healthcare providers asked you whether you wanted to use eHealth applications during your treatment, such as video calling, rehabilitation apps, sensors, or other applications?	Yes; No; I do not know	F
Did you use eHealth applications such as video calling, sensors, a rehabilitation app, or other applications during your treatment?	No (why not?) > I did not want to; I cannot deal with that; HCPs did not think it was necessary; I do not know; other… (open answer); Yes (which ones?) > sensors; videocalls; rehabilitation application; other… (open answer)	F
When did you use these eHealth applications?	During inpatient care; during home-based care	F
Questions about the usability and feasibility of the sensor		
Why do you think the sensor is used during your rehabilitation?	To become more aware of my movement; to become more aware of my sitting; to change my activity pattern; so the therapist can see what I am doing; I do not know; other... (open answer)	U
Did you trust the information the sensor gave you?	Yes, fully; yes, a little bit; no	U
How easy or difficult did you find using the sensor?	I thought the use of the sensor was… difficult; not easy, not difficult; easy	U
To what extend did using the sensor have added value for you?	For me, the use of the sensor had... no added value; some added value; much added value The added value was…. (open answer)	B
What do you think are advantages of using the sensor during your rehabilitation?	(Open answer)	B
What do you think are disadvantages of using the sensor during your rehabilitation?	(Open answer)	B

Would you recommend using the sensor to other patients?	Yes of course; I am not sure; no, I would not recommend it	B
Have you been properly supported by your HCPs in using the sensor?	Yes, very well; yes, reasonably well; no, not well	F
What could have been improved in the support from the HCPs when using the sensor?	Nothing; the following… (open answer)	F
Did you have help from your loved ones when using the sensor?	Yes; no; not applicable	F

*Answer options are separated by a semicolon, F=Feasibility, U=Usability, B=Both usability and feasibility

SUPPLEMENTARY MATERIAL 3. DETAILED OUTCOMES OF MOVEMENT VARIABLES, DIVIDED PER SENSOR VERSION

Table 1. Outcomes of movement variables from inpatient data

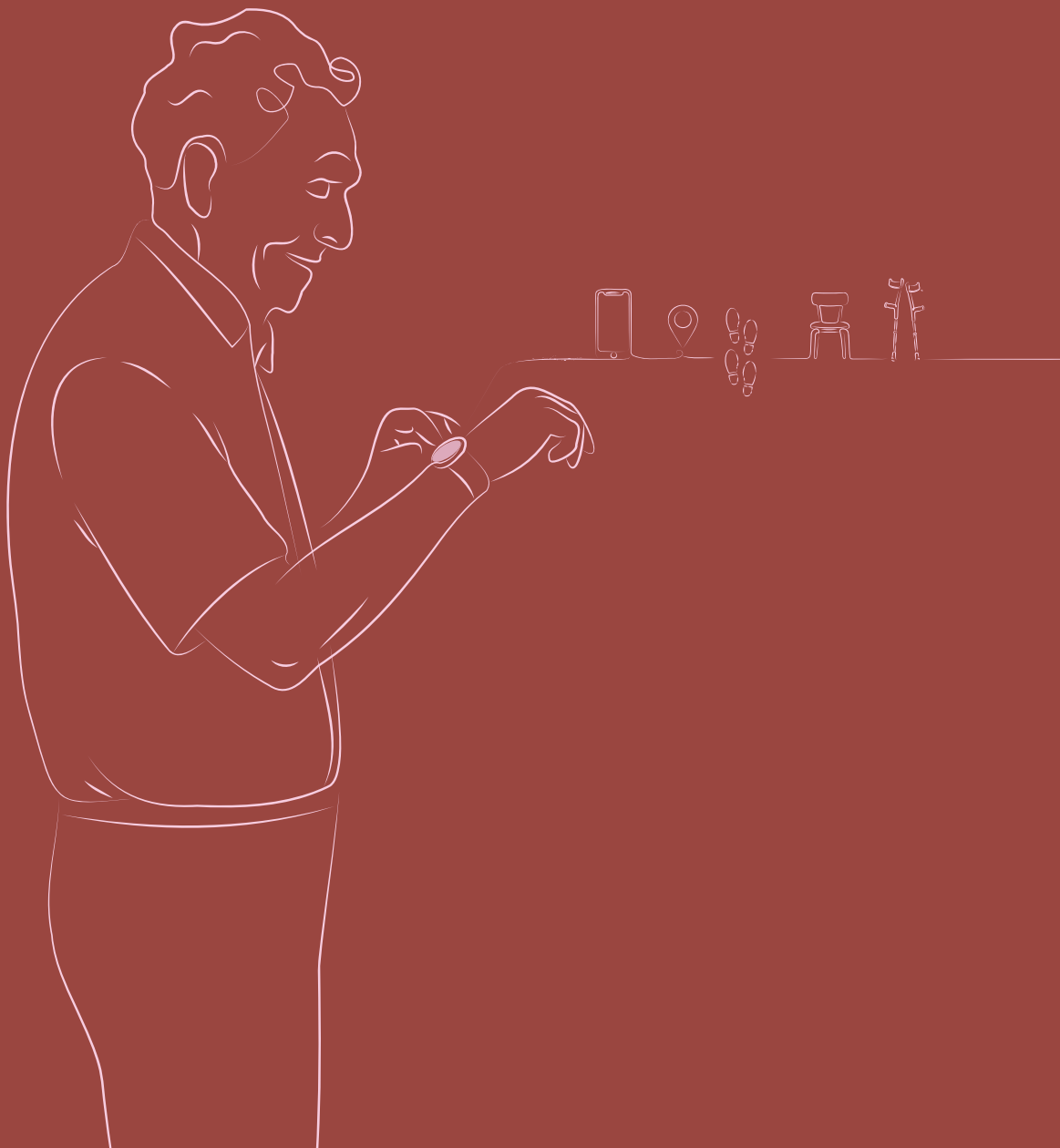
	All	**Type 1**	**Type 2.1**	**Type 2.2**
Movement during the day *Median (IQR)*	***N=23***	***N=5***	***N=6***	***N=13***
Wear time	730.0 (648.8 – 844.8)	788.6 (688.8 – 870.4)	793.3 (657.3 – 1149.6)	730.0 (648.7 – 844.8)
%Spent in SB	93.0 (81.2 – 97.3)	99.5 (96.7 – 99.0)	96.5 (94.6 – 98.0)	85.7 (79.1 – 92.3)
Minutes in SB	665.8 (599.5 – 743.6)	743.6 (688.1 – 864.0)	760.8 (639.3 – 1085.5)	623.9 (579.0 – 672.2)
%Spent in LPA	6.9 (2.4 – 18.7)	0.5 (0.1 – 3.3)	3.2 (2.0 – 5.1)	14.3 (7.7 – 20.7)
Minutes in LPA	49.9 (25.5 – 126.7)	6.0 (0.6 – 25.9)	26.2 (16.3 – 43.8)	105.8 (56.1 – 164.8)
%Spent in MVPA	0.0 (0.0 – 0.2)	0.0 (0.0 – 0.0)	0.3 (0.1 – 0.3)	0.0 (0.0 – 0.1)
Mean minutes in MVPA	0.3 (0.0 – 1.0)	0.0 (0.0 – 0.0)	2.1 (0.9 – 2.8)	0.3 (0.2 – 0.4)
PAM score	5.8 (3.7 – 11.0)	4.1 (3.5 – 8.7)	3.4 (2.3 – 5.5)	10.0 (5.6 – 14.3)
Bouts*	***N=19***	**n.a.**	***N=6***	***N=13***
Number of bouts	37.9 (20.4 – 58.6)	n.a.	19.4 (12.3 – 29.1)	50.2 (30.4 – 71.4)
%Spent in bouts 31-60 minutes	16.2 (10.6 – 20.3)	n.a.	13.4 (9.5 – 19.8)	16.5 (12.7 – 20.5)
Time in bouts 31-60 minutes	128.4 (88.0 – 147.8)	n.a.	130.2 (62.7 – 162.3)	125.6 (91.5 – 149.8)
%Spent in bouts >60 minutes	42.4 (29.2 – 67.1)	n.a.	72.9 (56.4 – 82.2)	34.6 (18.7 – 43.6)
Time in bouts >60 minutes	323.5 (191.4 – 28.3)	n.a.	541.6 (520.2 – 692.4)	223.8 (132.6 – 361.2)
Bout length	22.7 (10.0 – 34.3)	n.a.	43.2 (30.2 – 64.3)	11.5 (8.5 – 23.0)
W50	24.0 (6.0 – 77.0)	n.a.	81.0 (27.3 – 135.8)	9.0 (5.5 – 24.0)

*Bout outcomes are derived only from sensors that measured every minute

Table 2. Outcomes of movement variables from home-based data

	All	Type 1	Type 2.1	Type 2.2
Movement during the day *Median (IQR)*	***N=19***	***N=5***	***N=3***	***N=11***
Wear time	796.6 (707.8 0 959.0)	707.8 (603.1 – 870.6)	n.a.	796.6 (724.0 – 959.0)
%Spent in SB	90.5 (79.9 – 97.7)	99.0 (98.2 – 100.0)	n.a.	86.9 (76.0 – 90.5)
Minutes in SB	704.2 (600.4 – 896.4)	704.2 (599.0 – 862.1)	n.a.	675.1 (597.9 – 754.7)
%Spent in LPA	9.5 (2.3 – 19.8)	1.0 (0.0 – 1.8)	n.a.	13.0 (9.5 – 23.9)
Minutes in LPA	90.6 (16.7 – 177.3)	3.6 (0.4 – 12.3)	n.a.	149.9 (90.6 – 186.0)
%Spent in MVPA	0.0 (0.0 – 0.2)	0.0 (0.0 – 0.0)	n.a.	0.0 (0.0 - 0.2)
Mean minutes in MVPA	0.3 (0.0 – 1.6)	0.0 (0.0 – 0.0)	n.a.	0.3 (0.1 – 1.9)
PAM score	8.8 (5.3 – 14.9)	5.3 (4.7 – 7.9)	**n.a.**	12.6 (7.9 – 15.1)
Bouts*	***N= 14***	**n.a.**	***N=3***	***N= 11***
Number of bouts	55.5 (37.5 – 78.8)	n.a.	n.a.	57.3 (42.5 – 77.2)
%Spent in bouts 31-60 minutes	17.7 (11.4 – 21.9)	n.a.	n.a.	19.1 (14.8 – 21.5)
Time in bouts 31-60 minutes	147.4 (102.6 – 203.1)	n.a.	n.a.	150.0 (114.2 – 177.4)
%Spent in bouts >60 minutes	31.8 (187 – 40.4)	n.a.	n.a.	25.5 (15.2 – 38.8)
Time in bouts >60 minutes	275.6 (165.8 – 448.1)	n.a.	n.a.	172.5 (160.8 0 342.5)
Bout length	14.9 (9.4 – 20.3)	n.a.	n.a.	14.7 (7.9 – 17.8)
W50	30.0 (19.0 – 46.3)	n.a.	n.a.	25.0 (10.0 – 38.0)

*Bout outcomes are derived only from sensors that measured every minute



Chapter 6

Comparing sedentary behaviour after a transient ischemic attack or minor stroke in hospital-at-home and conventional hospitalization pathways: An exploratory trial

Suzanne Debeij
Marián Muchada
Marta Rubiera
Maria Giné-Garriga
Nicoletta Brunelli
Federica Rizzo
Jules Kraaijkamp
Miriam Haaksma
Wilco Achterberg
Eléonore van Dam van Isselt

Submitted

ABSTRACT

Background and aims: High sedentary time is associated with adverse stroke-related outcomes. This study explores the influence on sedentary time of NoraHome (a hospitalization-at-home program using digital monitoring through the NoraHome platform), compared with conventional hospitalization pathways, for adults aged 65 years or older with transient ischemic attack (TIA) or minor stroke.

Methods: This exploratory substudy enrolled stroke patients from both arms of the NoraHome randomized clinical trial (hospital-at-home vs. conventional hospitalization). All participants wore an activity monitor (ActivPAL) continuously for seven days in the first week after stroke and again after three months. Primary outcomes were differences in median sedentary time and percentage of sedentary time at both timepoints, tested with the Mann-Whitney U test. Secondary outcomes included measures of sedentary behaviour and physical activity.

Results: Fifteen patients were allocated to NoraHome and thirty to the control group. In the first week after stroke, both groups spent over 11 hours, or 78% per day sedentary (difference = 2.8% p=0.77). After three months, patients in both groups sat approximately 10 hours a day (difference = 2.4% p=0.62). Differences in secondary outcomes were also not significant.

Conclusions: Similar outcomes in NoraHome and conventional hospitalization groups indicate that hospital-at-home with NoraHome did not have a clear influence on the sedentary behaviour of older adults during the acute and subacute phase of stroke. The unexpected sedentary behaviour of patients during home-hospitalization warrants further research.

Key words: *sitting, stroke, home hospitalization, eHealth, activity monitoring*

INTRODUCTION

In the acute phase of stroke, stroke survivors spend more than 90% of their total daytime in sedentary behaviour (SB)[1]. SB is defined as any waking behaviour with an energy expenditure of ≤ 1.5 Metabolic Equivalent of Task (METs) while in a sitting, reclining or lying position[2]. This is concerning, because modifiable lifestyle factors such as low levels of physical activity and high amounts of SB are known risk factors for stroke and stroke recurrency[3]. High sedentary time, independently of low physical activity, is associated with less functional recovery, poor control of vascular risk factors and adverse health outcomes[4, 5]. The risks associated with high sedentary time relate both to the total duration of SB and to the occurrence of prolonged uninterrupted bouts of sitting[6, 7]. Reducing total sedentary time and modifying SB patterns may help reduce the risk of recurrent stroke.

The physical environment influences people's SB. For example, the hospital setting can discourage activity due to care being centered around the bed, and dependency on healthcare professionals[8]. Nevertheless, having a stimulating environment is important for recovery[9]. Physical activity can be stimulated by the ward's design and architecture, the organizational culture of the department and eHealth interventions[10, 11]. An environment that might naturally promote physical activity or influence activity patterns throughout the day is the patient's own home, as it encourages engagement in incidental and usual activities such as domestic tasks performed before the stroke[12]. After discharge from the hospital, patients spend up to 45 minutes less per day sitting compared with their time in the hospital[12, 13]. Both the total sedentary time and number of prolonged sitting bouts (exceeding 30 and 60 minutes) significantly decrease after discharge[12].

Building on these observations, a strategy to reduce SB in the early phase after a stroke might be to change the environment to the home setting. Hospital at Home (HaH) is a care model that safely allows patients to receive the necessary medical treatment in the comfort of their own homes[14]. Its application may also contribute to the reduction of SB. For patients with mild to moderate stroke, HaH is feasible, provides a smooth transition home, and can reduce long-term dependency[15]. Patients often feel more independent and in control in their own environment, while still receiving care and support from healthcare professionals[16]. To complement in-person healthcare provision, the integration of eHealth such as mobile applications into HaH may further enhance recovery

by increasing disease awareness, improving functional status, promoting healthy lifestyle and potentially reducing sedentary time[17-19].

Although the risks associated with high sedentary time are well known, the impact of HaH on SB outcomes, including sedentary time and patterns, has not been investigated[20]. Measuring SB during the acute and subacute stroke phase could provide additional insights into the influence of HaH compared with conventional hospitalization pathways. Most importantly, it could identify early opportunities for individualized interventions aimed at modifying this behaviour. Therefore, this exploratory study aims to examine the influence of HaH for older adults with transient ischemic attack (TIA) or minor stroke on sedentary time during the first week after stroke and at three months, compared with conventional hospitalization. We hypothesized that older adults receiving HaH in the acute phase of stroke may reduce sedentary outcomes faster than those following conventional hospitalization. Additionally, the study explores the influence of HaH on the number and pattern of prolonged sedentary bouts, sit-to-stand transitions, step count, and time spent standing and walking during the first week after stroke, and we aimed to explore if this difference in SB was maintained along follow-up.

METHODS

Design and participants

The NoraHome-SIT study is a quantitative exploratory study embedded in the NoraHome randomized controlled trial (ClinicalTrials.gov, NCT07500116). The NoraHome study aims to validate that the HaH program with the Nora application for patients with TIA or minor stroke is an efficient strategy compared to conventional hospitalization, with the same level of safety for the patient. The study was reviewed and approved by the Institutional Ethics Committee (PR(AG)387/2023) and is currently ongoing and still recruiting patients. The reporting of this study follows CONSORT guidelines (see Supplementary material 1).

All participants were recruited in the emergency department (ED) at Vall d'Hebron University Hospital (Barcelona, Spain). Patients were eligible to participate in the NoraHome study if they had 1) TIA (recovery of neurological deficits in <24h) or minor stroke (baseline National Institute of Health Stroke Scale [NIHSS] ≤ 5), 2) Smartphone available for the patient or caregiver, 3)

Family and/or formal caregiver support, 4) clinical stability during the previous 12 hours in the ED and 6) signed informed consent. Exclusion criteria were severe stenosis or symptomatic arterial occlusion that required patient hospital admission for potential reperfusion treatments and any pre-existing clinical or social factors that could preclude safe and adequate follow-up.

Participants were randomly allocated to the NoraHome or conventional hospitalization group (control) using a randomization platform (Studyrandomizer.org) with permuted block randomization. Stratification by sex was performed to ensure balance between arms. Due to the nature of the intervention, treatment allocation was not blinded.

Data collection for NoraHome-SIT took place between February and August 2025. During this recruitment period, all patients aged 65 years or older who met the inclusion criteria and were enrolled in the NoraHome study were also included in the NoraHome-SIT study. Participants who refused randomization for NoraHome were invited to participate in NoraHome-SIT and assigned to either HaH or conventional hospitalization based on their personal preferences.

The sample size was determined based on anticipated recruitment rates and the available study period. A target of twenty-five randomized participants per group was considered feasible and sufficient for this explorative study.

Procedures

Patients that consulted in the ED with a clinical diagnosis of TIA or minor stroke were evaluated for eligibility. They were monitored in the ED for a minimum of 12 hours and received diagnostic and therapeutic management according to national and international stroke guidelines[21]. All participants, or a legal representative, signed informed consent prior to inclusion.

NoraHome

Participants in the NoraHome arm received the same level of diagnostic workup and pharmacological treatment as in conventional clinical practice, but within the NoraHome hospitalization program. This encompasses the follow-up through a hybrid digital monitoring tool, Nora, and in-person follow-up at home by the HaH Vall d'Hebron team. Further details can be found in the NoraHome protocol (ClinicalTrials.gov, NCT07500116). After discharge from HaH, patients continued the follow-up through Nora application for 3 months. Within NoraHome, participants could chat with healthcare professionals,

confirm medication compliance, receive health information, and fill out questionnaires[18].

Conventional hospitalization

Participants in the control group were admitted to the stroke unit or the conventional neurology ward after the ED stay, and received conventional hospitalization to complete the etiological work-up and to adjust secondary prevention treatment according to the stroke etiology, in accordance with local protocols and usual clinical practice guidelines, based on clinical characteristics and stroke subtype[21]. After discharge, patients in the control group could also use the Nora application for follow-up.

NoraHome-SIT

For all participants in NoraHome-SIT, a thigh-worn posture-sensitive accelerometer (ActivPAL) was placed during the ED stay to wear for a week. At three months (90 ± 14 days) after the ED visit, participants returned to the hospital to be fitted with the same device and wore it for an additional week. Patients in the NoraHome group received educational material on SB (including a video and an infographic with practical recommendations to reduce sedentary time) delivered through the Nora application. Patients in the control group did not receive educational material on SB. All patients were instructed to fill out a sleep diary during the sensor motoring period.

Instruments

SB and physical activity were measured using a thigh-worn posture-sensitive accelerometer (ActivPAL; PAL Technologies Ltd., Glasgow, UK; size: 53 × 35 × 7 mm; weight: 15 g) containing a triaxial accelerometer sampling at 20 Hz with a dynamic range of ±2 g. Participants wore the device continuously for seven consecutive days during the first week after inclusion and again for seven days at the 3-month evaluation. The ActivPAL was positioned on the anterior medial aspect of the unaffected thigh, sealed with a waterproof nitrile sleeve, and secured to the skin using hypoallergenic adhesive dressing. This configuration allowed continuous 24-hour wear, including during water-based activities.

After device retrieval, data were downloaded using the manufacturer's software (PALanalysis v9.1.0.102; PAL Technologies Ltd.). The proprietary event-based algorithm classified posture and activity into sitting/lying, standing, and stepping, and generated variables including time spent sedentary, standing

time, stepping time, sit-to-stand transitions, and daily step counts. A 24-hour wear protocol was used to capture habitual movement behaviours.

Raw event files were visually inspected by the research team and cross-checked with participant sleep diaries and field notes to identify non-wear periods, bedtimes, and wake times. Valid monitoring days were defined as ≥14 hours of waking wear time, and only valid days were included in the analyses. This approach is consistent with previously published ActivPAL data-processing procedures used to identify valid waking wear time and classify SB in free-living conditions with stroke patients[22]. The device had to be worn for a period of at least four valid days for data to be included in the analysis.

Outcomes

The primary outcomes were the differences in median objectively measured sedentary time and percentage of sedentary time between groups during the first week after stroke. Secondary outcomes included the between-group differences in outcomes related to sedentary behaviour: number of sit-to-stand transitions; number of and absolute time spent in prolonged bouts of 31-60 minutes and >60 minutes, and outcomes related to physical activity: daily step count; the median minutes spent standing; stepping; in light physical activity (LPA; 1.5 to <3.0 METs), and moderate to vigorous physical activity (MVPA; ≥ 3 METs), representing upright and ambulatory activity); the α; half-life bout duration. Additionally, outcomes include the total sedentary time and percentage of sedentary time at 3-month evaluation[23]. The half-life bout duration is defined as the length of the sedentary time corresponding to 50% of the daily accumulated sedentary time[24]. The α was calculated to show the frequency distribution of bout durations. A smaller value of alpha indicates a distribution with longer sedentary bouts, while a larger value suggests a dominance of shorter bouts.

Statistical Analysis

Descriptive statistics were used to examine the characteristics of study participants. Only data marked as *awake* and from days marked as *valid* were analyzed. First, per person, the mean sedentary time per day and mean percentage of sedentary time across the first week and after three months was calculated. Thereafter, per group, the median was calculated. Because sample sizes were small, the median and interquartile range (IQR) was described as the summary measure on both timepoints. The Mann-Whitney U test was carried out to test the difference between the NoraHome and control group.

Also, descriptive plots were used to visualize the daily proportion of sedentary time per participant. Furthermore, the number and duration of sedentary bouts per day (30-60 and >60 minutes), time and percentage spent standing and walking, number of sit to stand transitions and time spent in LPA and MVPA of the first week were first calculated per person and then per group. Median differences between groups were determined. In addition, the alpha and the weighted median bout duration were calculated. *α* was calculated with $\alpha = 1 + n[\sum_{i=1}^{n} ln\frac{x_i}{xmin}]^{-1}$ with X_i with being the observed sedentary bout lengths[25]. For these secondary outcomes, the median (IQR) was described as the summary measure. Statistical analyses were performing using IBM SPSS statistics version 29, with statistical significance set as $p<0.05$.

RESULTS

Of the 58 eligible patients, 45 patients agreed to participate. Of these patients, 36 were randomly assigned to the control (N=24) and NoraHome (N=12) groups; 9 patients were included in the observational cohort, according to their preference (NoraHome N=3, Control N=6). Flowchart is presented in Figure 1. Due to NoraHome-SIT being part of the NoraHome trial, participants for this substudy were not equally distributed between groups. Fifteen participants were included in the NoraHome group and thirty in the control group. ActivPAL data from week 1 was incomplete for 13 patients (28.9%) due to invalid measurement (N=6), flat battery (N=4), or loss of device (N=3). During the study period, only 25 patients reached the three-month follow-up and could be evaluated at this timepoint. In the main analysis results are reported for all participants. Analyses restricted to randomized patients are available in supplementary material 2.

Participants' characteristics are described in detail in Table 1. The mean age of the included patients was 80.9 ± 9.5 years in the control group, and 75.5 ±7.6 years in the NoraHome group. In the control group, 50% of the participants were female, in the NoraHome group this was only 20%. Most patients were included after suffering from TIA. Ten patients in the control and four in the NoraHome group were discharged during the wearing week.

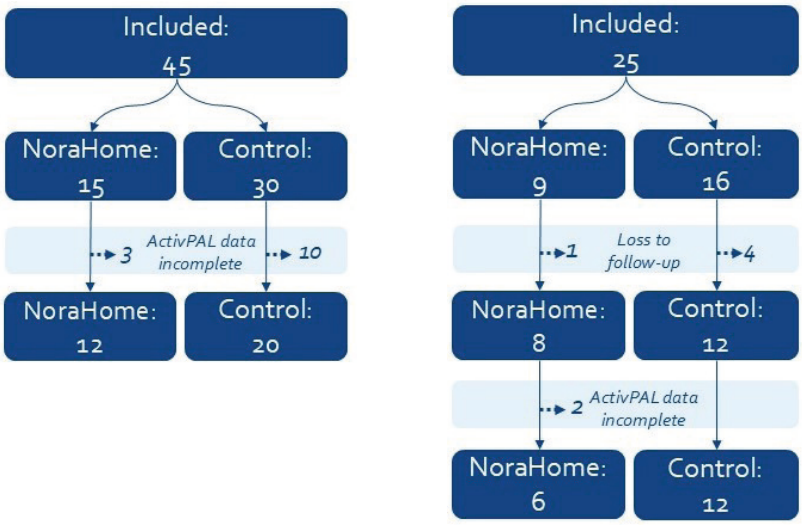


Figure 1. Flowchart of inclusion for a) week 1, and b) month 3

Sedentary behaviour

Median sedentary time in the first week after stroke was 698.2 (662.3 - 803.0) minutes for the NoraHome group and 679.3 (565.5-700.8) minutes for the control group (difference = 18.9, p=0.18). The sedentary times correspond to a percentage of SB during wake-hours of 81.4% (73.7 - 87.5%) for the NoraHome group and 78.6% (65.2 - 89.3%) for the control group (p=0.77). See table 2 and figure 2 for details. Results did not change if patients' data were analyzed as-treated data or data from only randomized patients were included (see supplementary material 2). The median percentage of sedentary time per day followed a similar pattern in both groups during the first week (figure 2).

Median sedentary time three months after stroke was 596.1 (523.6 - 689.0) minutes in the control group, and 617.4 (526.2 - 730.3) minutes in the NoraHome group (p=0.77). This corresponds to 68.1% (60.9 - 82.1%) spent sedentary in the NoraHome group and 65.7% (57.1 - 74.3%) in the control group (difference =2.4%, p=0.62). The median percentage sedentary time remained similar in both groups during the wearing week after three months (figure 2).

Table 1. Participant characteristics

Characteristic	Control N=30	NoraHome N=15
Age (SD)	80.9 (9.5)	75.5 (7.6)
Female (N (%))	15 (50)	3 (20.0)
BMI	27.4 (5.1)	26.7 (3.4)
Diagnosis (%)		
TIA	17 (56.7)	8 (53.3)
Ischemic stroke (IS)	12 (40.0)	6 (30.0)
Hemorrhagic stroke	1 (3.3)	-
Stroke mimic	-	1 (6.7)
TIA/IS Etiology (TOAST classification) (%)		
Lacunar	12 (40.0)	8 (53.3)
Undetermined etiology	11 (36.7)	5 (33.3)
Atherosclerosis	3 (10.0)	-
Cardio embolism	2 (6.7)	1 (6.7)
Inhabitual	1 (3.3)	-
Median days of care (IQR)	6.0 (5.0-8.0)	8.0 (2.0 – 14.0)
Admission mRS 0-2 (N (%))	23 (76.7)	13 (86.7)
Discharge mRS 0-2 (N (%))	17 (56.7)	9 (60.0)
3-month mRS 0-2 (N (%))	19 (63.3)	8 (53.3)
Median admission NIHSS (IQR)	0.5 (0.0 – 3.0)	1.0 (0.0 – 2.0)
Median discharge NIHSS (IQR)	0.0 (0.0 – 1.0)	0.0 (0.0 – 0.0)
Median 3-month NIHSS (IQR)	0.0 (0.0 – 1.0)	0.0 (0.0 – 1.0)

BMI = Body Mass Index, mRS = modified Ranking Scale, NIHSS = National Institutes of Health Stroke Scale

In the secondary sedentary related outcomes, differences between groups were small, and probably without clinical impact (see Table 3). Patients in the NoraHome group spent median 11.2 minutes more in bouts of 30-60 minutes per day than the control group and 62.4 minutes less in bouts of 60 minutes or more. The half-life bout duration was 12.6 minutes less in the NoraHome group than in the control group.

Table 2. Medians of total sedentary time and percentage of time spent sedentary

first week after stroke				
Median	**Study arm**		**Median difference**	**P value**
	Control (N=20)	**NoraHome (N=12)**		
Sedentary time per day in minutes (IQR)	679.3 (565.5 - 700.8)	698.2 (662.3 - 803.0)	-18.9	0.18
% of time per day spent sedentary (IQR)	78.6 (65.2 - 89.3)	81.4 (73.7 - 87.5)	-2.8	0.77
three months after stroke				
Median	**Study arm**		**Median difference**	**P value**
	Control (N= 12)	**NoraHome (N= 6)**		
Sedentary time per day in minutes (IQR)	596.1 (523.6 - 689.0)	617.4 (526.2 - 730.3)	-21.3	0.89
% of time per day spent sedentary (IQR)	65.7 (57.1 - 74.3)	68.1 (60.9 - 82.1)	-2.4	0.62

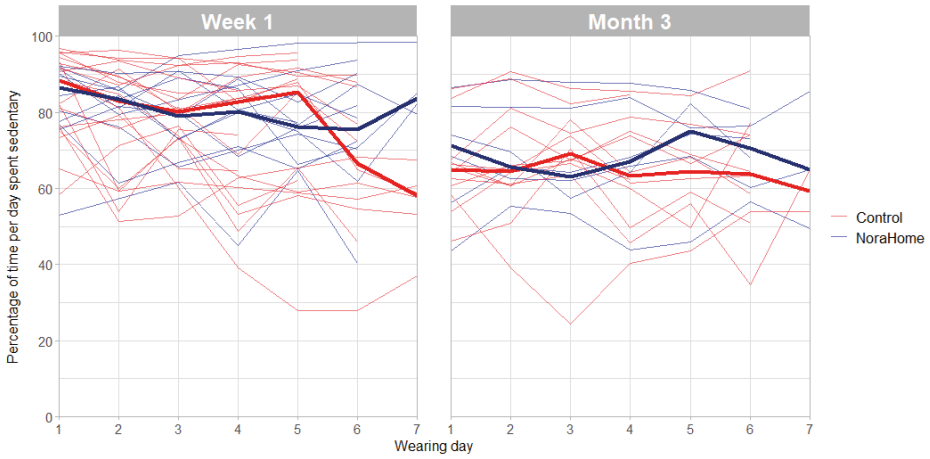


Figure 2. Visualization of the percentage of daily time spent sedentary per person (thin lines), and the median percentage per group (thick lines) for the first week after stroke (left), and for the follow-up week after three months (right).

Table 3. Secondary sedentary behaviour and physical activity related outcomes in the first week after stroke

Median (IQR)	Control *(N=20)*	NoraHome *(N=12)*	Median difference
Sedentary behaviour related outcomes			
Number of bouts of 30-60 minutes per day	3.3 (2.6 – 4.3)	3.6 (3.2 – 5.5)	-0.3
Minutes spent in bouts of 30-60 minutes per day	138.3 (114.6 – 186.9)	149.5 (135.5 – 236.2)	-11.2
Number of daily bouts of >60 minutes	3.2 (2.5 – 4.2)	3.5 (2.6 – 4.2)	-0.3
Minutes spent in bouts of >60 minutes per day	391.6 (232.3 – 447.8)	329.2 (253.5 – 493.8)	62.4
Half-life bout duration	65.4 (46.0 – 78.6)	52.8 (48.0 – 72.1)	12.6
Number of sit to stand transitions	30.5 (25.4 – 44.1)	37.1 (30.1 – 40.6)	-6.6
Alpha	1.5 (1.4 – 1.5)	1.5 (1.4 – 1.5)	0.0
Physical activity related outcomes			
Step count	3336.5 (968.4 - 7097.1)	2546.9 (1407.0 - 4025.7)	789.6
Minutes spent standing	136.5 (72.3 - 229.3)	113.5 (92.9 - 207.0)	23.0
% of time awake spent standing	15.6 (9.0 - 23.4)	12.9 (10.1 - 22.3)	2.7
Minutes spent walking	51.8 (13.8 - 84.3)	39.9 (22.2 - 52.6)	11.9
% of time awake spent walking	5.9 (1.7 - 9.0)	4.1 (2.5 - 6.6)	1.8
Minutes spent in LPA	64.0 (20.8 - 95.8)	60.3 (36.0 - 78.3)	3.7
% of time awake spent in LPA	7.8 (2.6 - 10.1)	7.3 (4.1 - 8.6)	0.5
Minutes spent in MVPA	12.3 (3.5 - 44.1)	6.1 (3.1 - 19.6)	6.2
% of time awake spent in MVPA	1.4 (0.4 - 4.8)	0.7 (0.3 - 2.3)	0.7

LPA= Light Physical Activity, MVPA= Moderate-Vigorous Physical Activity

Physical activity

In all physical activity related outcomes, the control group showed to be slightly more active, but differences were small probably without clinical impact. All outcomes are shown in Table 3. Median step count was 798.6 steps higher in the control group than in the NoraHome group. Participants in the Control

group spent 23.0 minutes more standing and 11.9 minutes more walking than in the NoraHome group.

DISCUSSION

This study explored the influence of HaH on sedentary time in older adults with TIA or minor stroke during the early phase after acute stroke, compared with conventional hospitalization.

In the first week after stroke, there was no difference time spent sedentary in both groups; spent over 11 hours per day sedentary; (18.9 minutes; p=0.18). After three months, SB was still similar between groups (21.3 minutes; p=0.89). Differences in secondary outcomes in the first week after stroke were also irrelevant. This indicates that in our study, HaH with NoraHome did not have a clear influence on SB during the acute and subacute phase of stroke.

Although methods and outcomes measures vary across studies, the SB in our population aligns with previous findings. Earlier research shows that patients in the first week after stroke spend on average between 69% and 94% of their waking hours sedentary, compared to approximately 80% in our study population[26-28]. This high level may reflect physical or psychological consequences of stroke, post-stroke fatigue, or reduced confidence but could also reflect limited awareness of their movement behaviour and of the health risks associated with prolonged sedentary time[29]. After three months, SB typically remains high, although some studies have also described that sedentary time decreases by up to 40 minutes, which is comparable to the reduction we observed over time[30]. These changes over time may be driven by both natural recovery and behavioural changes.

There could be several reasons why sedentary time was similar in both groups. Firstly, because participants presented minor symptoms, some participants in the control group were discharged early during the first week. While this reflects real-world clinical practice, this may have diminished the contrast between groups. Secondly, while patients in conventional hospitalization had freedom of movement on the ward and received early mobilization and physiotherapy to prevent loss of function, whereas this was not available for patients in HaH. Furthermore, although one stroke study suggested that the change in environment might explain their observed change in SB among

participants recovering at home, findings from other hospitalized populations suggest that changing the environment may be insufficient to counteract the systemic effects of acute illness on functional ability and associated movement behaviour[31, 32]. Ongoing impairments, emotional challenges, fatigue and adapting to new functional limitations at home may have influenced movement behaviour, as patients in HaH may continue to adopt a 'patient role' focusing on rest and recovery and perceive reduced safety when moving around the home[33-36]. These factors together may explain why a change in environment did not lead to notable differences in this study.

Accurately capturing SB is essential for interpreting findings, which underscores the need to examine the quality of measurements in this study. Although the ActivPAL is often considered the gold standard for measuring movement behaviour, we encountered issues with recordings for almost one-third of the participants. While the device has demonstrated high validity in healthy, adult populations under both laboratory and free-living conditions (>90%), evidence in populations with impairments in community and hospital is limited and findings are mixed[37-41]. Although a study with an older stroke cohort study reported high accuracy in classifying sedentary positions and sit-to-stand transitions, several studies in other populations also reported that measurement error may increase at slower walking speeds[37, 40]. Slow walking speeds, together with other impairment-related differences in gait and posture may challenge the device's automated algorithms. Future work may benefit from optimization and population-specific validation of algorithms for individuals with impaired mobility.

Strengths and limitations

To the authors' knowledge, this is the first study directly comparing the SB of older stroke patients receiving HaH with those receiving conventional hospitalization. The measurement period of this study, both in the acute and subacute phase, provided valuable insight into movement behaviour of patients with TIA or stroke. Additionally, randomized allocation in this exploratory design strengthens the internal validity of this study and reduces the risk for selection bias. However, several limitations should be acknowledged. Although randomization was performed using a computerized system, the final distribution between study arms was unequal and sex stratification was not optimal because it was part of a larger study. This may have influenced the results. Furthermore, the sample size was smaller than anticipated, potentially

reducing the statistical power to detect differences between groups. Lastly, LPA and MVPA may have been underestimated by the ActivPAL.

CONCLUSION

In this exploratory study, Hospital-at-Home did not show a clear influence on sedentary time of older adults with TIA or minor stroke during the first week after stroke, nor after three months, compared with conventional hospitalization. Total sedentary time and percentage of sedentary time were comparable across groups. Nevertheless, this absence of differences is not evidence of absence, and additional research is needed to clarify possible benefits of Hospital-at-Home on sedentary behaviour. Future studies may benefit from more critically selecting the population at-risk of delayed discharge, to maximize the impact of the HaH interventions. Further, given the challenges of accurately capturing sedentary behaviour for this population, future studies may benefit from sensors that are optimized to measure sedentary behaviour for older people with impairments. Finally, future studies should explore how Hospital-at-Home models can be optimized to support the reduction of sedentary behaviour, for example through including home-based physiotherapy.

STATEMENTS

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Competing interests

All authors declare that they have no competing interests.

Compliance with Ethical Standards

The study was reviewed and approved by the Institutional Ethics Committee (PR(AG)387/2023) of the Vall d'Hebron University Hospital.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT and Copilot in order to improve readability and language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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SUPPLEMENTARY MATERIAL 1. CONSORT 2025 CHECKLIST

CONSORT 2025 checklist of information to include when reporting a randomised trial*

Section / Topic	No	CONSORT 2025 checklist item description	Reported on page no.
Title and abstract			
Title and structured abstract	1a	Identification as a randomised trial	134
	1b	Structured summary of the trial design, methods, results, and conclusions	132
Open science			
Trial registration	2	Name of trial registry, identifying number (with URL) and date of registration	134
Protocol and statistical analysis plan	3	Where the trial protocol and statistical analysis plan can be accessed	134
Data sharing	4	Where and how the individual de-identified participant data (including data dictionary), statistical code and any other materials can be accessed	x
Funding and conflicts of interest	5a	Sources of funding and other support (e.g., supply of drugs), and role of funders in the design, conduct, analysis and reporting of the trial	145-146
	5b	Financial and other conflicts of interest of the manuscript authors	145-146
Introduction			
Background and rationale	6	Scientific background and rationale	133-134
Objectives	7	Specific objectives related to benefits and harms	134
Methods			
Patient and public involvement	8	Details of patient or public involvement in the design, conduct and reporting of the trial	x

Trial design	9	Description of trial design including type of trial (e.g., parallel group, crossover), allocation ratio, and framework (e.g., superiority, equivalence, non-inferiority, exploratory)	134-136
Changes to trial protocol	10	Important changes to the trial after it commenced including any outcomes or analyses that were not prespecified, with reason	135
Trial setting	11	Settings (e.g., community, hospital) and locations (e.g., countries, sites) where the trial was conducted	134
Eligibility criteria	12a	Eligibility criteria for participants	134-135
	12b	If applicable, eligibility criteria for sites and for individuals delivering the interventions (e.g., surgeons, physiotherapists)	n.a.
Intervention and comparator	13	Intervention and comparator with sufficient details to allow replication. If relevant, where additional materials describing the intervention and comparator (e.g., intervention manual) can be accessed	134-136
Outcomes	14	Pre-specified primary and secondary outcomes, including the specific measurement variable (e.g., systolic blood pressure), analysis metric (e.g., change from baseline, final value, time to event), method of aggregation (e.g., median, proportion), and time point for each outcome	136-138
Harms	15	How harms were defined and assessed (e.g., systematically, non-systematically)	x
Sample size	16a	How sample size was determined, including all assumptions supporting the sample size calculation	135
	16b	Explanation of any interim analyses and stopping guidelines	n.a.
Randomisation:			
Sequence generation	17a	Who generated the random allocation sequence and the method used	135
	17b	Type of randomisation and details of any restriction (e.g., stratification, blocking and block size)	135
Allocation concealment mechanism	18	Mechanism used to implement the random allocation sequence (e.g., central computer/ telephone; sequentially numbered, opaque, sealed containers), describing any steps to conceal the sequence until interventions were assigned	135

Implementation	19	Whether the personnel who enrolled and those who assigned participants to the interventions had access to the random allocation sequence	135
Blinding	20a	Who was blinded after assignment to interventions (e.g., participants, care providers, outcome assessors, data analysts)	135
	20b	If blinded, how blinding was achieved and description of the similarity of interventions	n.a.
Statistical methods	21a	Statistical methods used to compare groups for primary and secondary outcomes, including harms	137-138
	21b	Definition of who is included in each analysis (e.g., all randomised participants), and in which group	137-138
	21c	How missing data were handled in the analysis	137-138
	21d	Methods for any additional analyses (e.g., subgroup and sensitivity analyses), distinguishing prespecified from post-hoc	
Results			
Participant flow, including flow diagram	22a	For each group, the numbers of participants who were randomly assigned, received intended intervention, and were analysed for the primary outcome	138-139
	22b	For each group, losses and exclusions after randomisation, together with reasons	138-139
Recruitment	23a	Dates defining the periods of recruitment and follow-up for outcomes of benefits and harms	135
	23b	If relevant, why the trial ended or was stopped	n.a.
Intervention and comparator delivery	24a	Intervention and comparator as they were actually administered (e.g., where appropriate, who delivered the intervention/comparator, how participants adhered, whether they were delivered as intended [fidelity])	138-139
	24b	Concomitant care received during the trial for each group	x
Baseline data	25	A table showing baseline demographic and clinical characteristics for each group	140

Numbers analysed, outcomes and estimation	26	For each primary and secondary outcome, by group: the number of participants included in the analysis the number of participants with available data at the outcome time point result for each group, and the estimated effect size and its precision (such as 95% confidence interval) for binary outcomes, presentation of both absolute and relative effect size	139-143
Harms	27	All harms or unintended events in each group	x
Ancillary analyses	28	Any other analyses performed, including subgroup and sensitivity analyses, distinguishing pre-specified from post-hoc	139
Discussion			
Interpretation	29	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	143-145
Limitations	30	Trial limitations, addressing sources of potential bias, imprecision, generalisability, and, if relevant, multiplicity of analyses	144-145

*We strongly recommend reading this statement in conjunction with the CONSORT 2025 Explanation and Elaboration and/or the CONSORT 2025 Expanded Checklist for important clarifications on all the items. We also recommend reading relevant CONSORT extensions. See www.consort-spirit.org.

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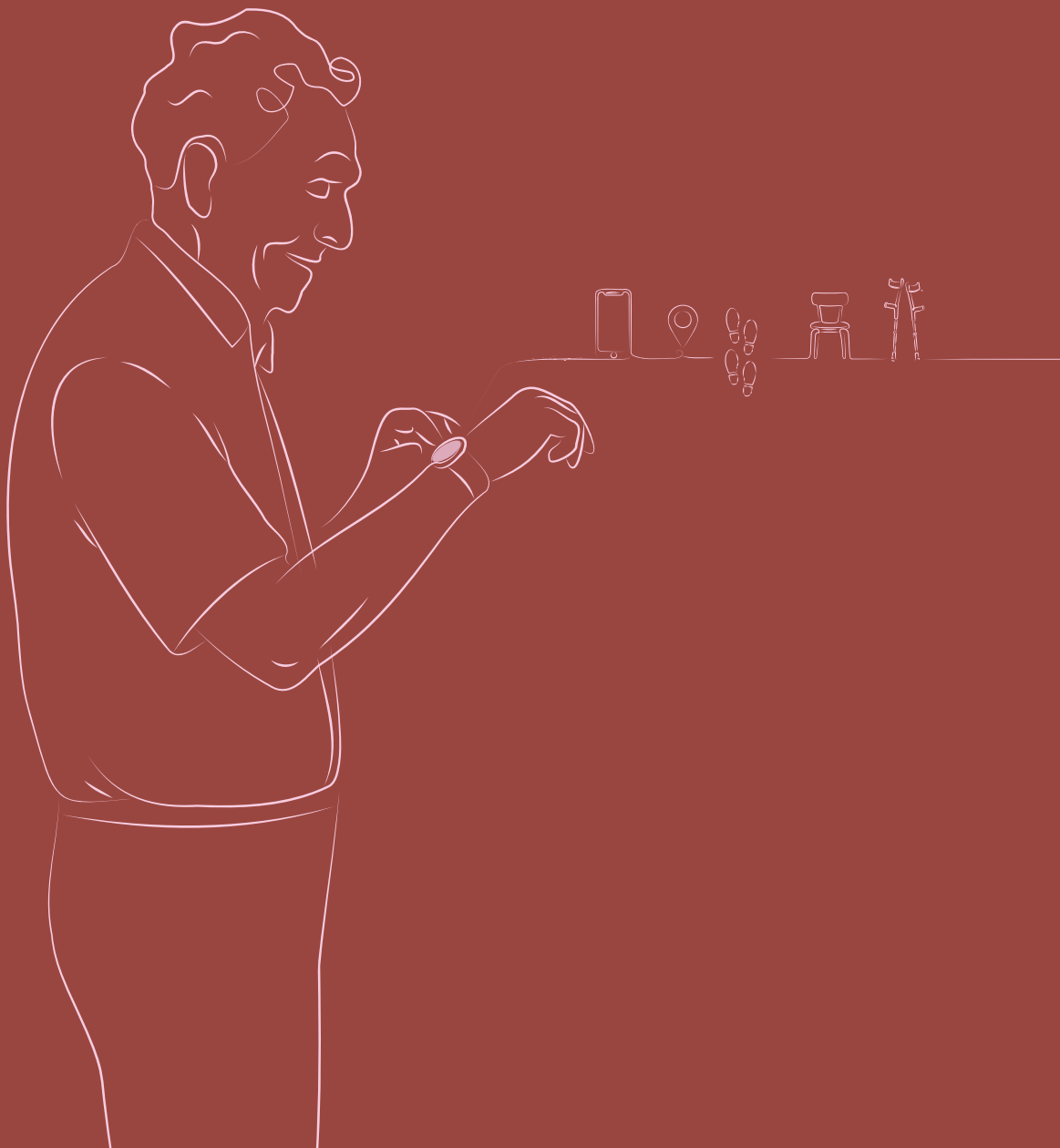
SUPPLEMENTARY MATERIAL 2. SENSITIVITY ANALYSES

Table 1. Medians of primary sedentary behavior outcomes of both wearing weeks; randomized data.

first week after stroke				
Median	Study arm		Median difference	P value
	Control *(N=17)*	NoraHome *(N=11)*		
Sedentary time per day in minutes (IQR)	666.5 (562.5 – 718.3)	688.3 (661.0 – 791.8)	21.8	0.24
% of time per day spent sedentary (IQR)	71.4 (64.5 - 88.3)	81.4 (72.8 – 84.3)	10	0.46
3 months after stroke				
Median	Study arm		Median difference	P value
	Control (*N=11)*	NoraHome *(N=6)*		
Sedentary time per day in minutes (IQR)	613.4 (561.8 – 703.3)	617.4 (526.2 – 730.3)	4.0	1.00
% of time per day spent sedentary (IQR)	66.1 (6.9 – 75.6)	68.1 (60.9 – 82.1)	2.0	0.73

Table 2. Medians of primary sedentary behavior outcomes of both wearing weeks; as-treated analysis of randomized data.

first week after stroke				
Median	*Study arm*		Median difference	P value
	Control (N=16)	NoraHome *(N=12)*		
Mean sedentary time per day in minutes (IQR)	671.1 (565.5 - 734.0)	677.8 (652.9 - 770.9)	-6.7	0.63
Mean % of time per day spent sedentary (IQR)	78.0 (65.2 - 88.9)	77.4 (69.4 - 83.2)	0.6	0.91
3 months after stroke				
Median	Study arm		Median difference	P value
	Control (*N=10)*	NoraHome *(N=7)*		
Sedentary time per day in minutes (IQR)	613.3 (543.9 - 713.7)	613.4 (539.6 - 725.8)	-0.1	0.89
% of time per day spent sedentary (IQR)	67.7 (60.0 - 78.0)	67.0 (64.7 - 80.7)	0.7	1.00



Chapter 7

General discussion and summary

GENERAL DISCUSSION

The use of wearable sensors in geriatric rehabilitation holds promise for supporting self-management and reducing sedentary behaviour. However, evidence regarding the use, usability, and feasibility of sensor monitoring in the geriatric rehabilitation context is limited. Therefore, this thesis aimed to provide evidence on how sensor monitoring technology can be used to support self-management among older adults during geriatric rehabilitation. Within self-management, this thesis focused on the use of sensor monitoring technology to reduce sedentary behaviour.

To achieve this aim, the following research question was addressed:

How can sensor monitoring technology be applied in geriatric rehabilitation to improve self-management and reduce sedentary behaviour?

This chapter summarizes and discusses the main findings of this thesis and the methodological decisions made throughout the process. Finally, implications and recommendations for clinical practice and policy, education, and future research are presented.

Main findings

Chapter 2 presents a qualitative study exploring the perspectives of healthcare professionals and patients on the potential use and value of a sensor-monitoring bracelet for patients with COPD at high risk for exacerbations. Overall, participants acknowledged that a monitoring bracelet could be beneficial and valuable. Participants particularly expected the technology to support self-management by identification of deviations from an individual's normal (vital) parameters, allowing for early detection of exacerbations, and subsequently alerting users.

To move beyond exploring the potential value of sensor monitoring, **chapter 3** assesses the perceived usability and feasibility of a sensor monitoring system developed for COPD patients at home that was iteratively adapted to geriatric rehabilitation. The system was frequently used by the participants and underwent several adaptations throughout the study. Nevertheless, further adjustments are needed for the system to be usable and feasible during geriatric rehabilitation.

In the subsequent chapters, the focus shifts to the role of sensor monitoring technology during geriatric rehabilitation in objective measurement and reduction of sedentary behaviour as a component of self-management, and the role of feedback therein. **Chapter 4** presents a systematic review assessing the effectiveness of interventions that use feedback from objective measurements to reduce sedentary behaviour in older adults during post-acute rehabilitation. Although some studies reported a reduction in sedentary behaviour following interventions incorporating objective feedback, the overall evidence regarding the effect of feedback on sedentary behaviour in geriatric rehabilitation remains inconclusive.

To advance the understanding of the influence of feedback on sedentary behaviour, **chapter 5** examines the perspectives of patients and healthcare professionals on the usability and feasibility of a sensor monitoring system that provides this feedback during both inpatient and home-based geriatric rehabilitation. Although participants acknowledged some aspects of the system as usable, concerns constrained its overall usability for both healthcare professionals and patients. The feasibility of the monitoring system and its use was perceived as sufficient, although in need of practical improvements.

To provide insight into the sedentary behaviour in the first week after transient ischemic attack (TIA) or minor stroke, **chapter 6** reports an exploratory study that examines this among older adults. This sub-study compared sedentary behaviour between patients receiving NoraHome (a hospitalization-at-home program using digital monitoring through the NoraHome platform) and those receiving conventional hospitalization. Similar outcomes in both groups indicate that Hospital-at-Home with NoraHome did not have a clear influence on the sedentary behaviour of older adults during the acute and subacute phase of stroke.

Evidence from this thesis shows that there are numerous factors to consider when applying sensor monitoring technology in geriatric rehabilitation to support self-management and address sedentary behaviour. Stakeholders in geriatric rehabilitation recognize that sensor monitoring technology can offer meaningful support for self-management, provided that the technology needs to fit the geriatric rehabilitation context. For technology to be usable and feasible, it must be easy to use from the start, deliver sufficiently accurate and clinically valid measurements, and be integrated into the rehabilitation program with clear goals and support from the team (chapters 2 through 6).

Further, this thesis shows that patients in geriatric rehabilitation sit most of the day (chapters 4 through 6), and there is currently no consensus on sedentary outcomes to report, nor on the most effective way to reduce sedentary behaviour or what reduction is clinically meaningful.

A broader perspective

In the following text, three of the findings will be discussed from a broader perspective: 1) accurate measurement, 2) consensus on sedentary outcomes & clinical validity, and 3) integration into the treatment program to change behaviour.

Accurate measurement

The importance of accurate measurement emerged across multiple chapters of this thesis (chapter 2, 3, 5, and 6). Although the use of the various sensor monitoring technologies described in these chapters had different aims, accuracy remained a central concern. The required degree of accuracy that is needed depends on the intended aim of the application of the sensor.

The goals of the use of activity monitoring sensors can broadly be divided into two categories: sensors designed to capture detailed, high-resolution information, and sensors designed to provide users with general insight into patterns and deviations. The first category is typically used in research to increase knowledge on a subject, such as the sedentary pattern of stroke survivors (like chapter 6). Because these sensors are not designed for direct feedback for the persons wearing them, they tend to be less user-friendly. They, for example, require computer access or have complex dashboards. In contrast, sensors aimed at providing general insights (such as devices used in chapter 2, 3 and 5), are often more user-friendly for clinical practice. These sensors, for example, offer continuous and easy-to-interpret feedback through on-device displays, connected apps or websites. Because they aim to provide users with general insight, this often comes at the expense of measurement accuracy. Consequently, which sensor suits best in a certain context is dependent on intended use. Both categories encompass a wide range of sensor types that differ in measurement method, parameters and provided level of detail.

Activity monitoring relies on motion sensors such as accelerometers or inclinometers (chapters 2 through 6)[1, 2]. Inclinometer-based devices, such as the ActivPAL (chapter 6), determine body posture by measuring the inclination of a body part, enabling detection of sitting, standing, or walking. Accelerometer-

based sensors, such as the Hipper (chapter 5), estimate activity levels by detecting movement intensity[1]. Despite differences in measurement method and aim of use, all sensors rely on algorithms that convert raw sensor data into meaningful output. A barrier is that validation studies of these algorithms have predominantly been conducted in healthy adult populations[3-5].

As a result, there is limited real-world validation for many parameters in geriatric rehabilitation. This is problematic, as individuals in this population might exhibit pathological and physiological changes that may require distinct validation[6]. Algorithms optimized for healthy adults may therefore underperform in geriatric rehabilitation. The scarcity of sensor monitoring technology tailored for this group poses a major barrier for reliable clinical and research applications. Beyond possible compromising in accuracy, validity and interpretability of the findings, such underperformance may also negatively influence patient and professional motivation and trust in the feedback provided. Instead of supporting self-management as intended, inaccuracy may lead to user fatigue, discourage sustained use, and negatively affect patient well-being[7, 8]. This can include reduced patient self-esteem, mental health problems and increased stress responses resulting in, for example, elevated blood pressure or heart rate[7, 8].

Given the risk that inaccurate measurement poses for the validity and interpretability of findings, as well as the potential for negative impact on the user, ensuring accurate sensor measurement in geriatric rehabilitation is essential for both scientific and clinical purposes. The need for optimized accuracy represents an important opportunity for improvement, which will also be addressed in the *implications and recommendations* section.

Consensus on sedentary outcomes & clinical validity

A consensus definition of sedentary behaviour has been available since 2017, and several studies have recommended which sedentary outcomes should be reported. Nevertheless, substantial variation remains in both the measurement methods and the outcomes presented, also within this thesis (chapters 4, 5 and 6)[1, 9-11]. These differences result in literature that is difficult to compare or synthesise and may contribute to the ongoing absence of clear thresholds across all populations for how much sedentary time is detrimental to health, as well as which differences are clinically relevant[12].

Current studies reporting sedentary behaviour differ in their methodological choices. For example, some include sleeping time while others exclude it, and among those that exclude it, operationalisation varies (e.g., fixed exclusion periods, the use of a sleeping diary or omission of afternoon naps)[1]. Studies also differ in the required wear-time per day, the minimum number of valid wear-days, and the criteria used to define a valid day[13]. In addition, there is an inconsistency in outcomes reported: some studies present only sedentary time (absolute or relative), whereas others also report pattern metrics such as bout duration. In this thesis (chapters 5 and 6), night-time sleep was excluded, participants were required to wear the device for at least four days, and both total sedentary time and pattern metrics were reported to provide a broader perspective on sedentary behaviour.

In 2022, a consensus by experts was reached on a core outcome set to report in interventional sedentary behaviour studies on adults[11]. But since studies differ in aim and populations, a single universal measurement approach is unlikely to fit all contexts and should be adapted to the study's aim and methodology. Nevertheless, to improve comparability across studies, further consensus trajectories are needed not only on which outcomes to include, but also on how these outcomes are operationalised and measured[8]. To facilitate the interpretation, replication, and synthesis of findings, clear and standardised guidance is needed. This guidance should define common performance metrics and clinical validation protocols, along with transparent and comprehensive reporting of data collection, data management, processing, analytical methods, and summary metrics[8, 13]. Such reporting guidance should be applicable across diverse populations, including geriatric rehabilitation.

Regarding how much sedentary time is detrimental to health, earlier literature on total sedentary time in older adults suggested a dose-response relationship with a clear threshold, indicating that sitting more than nine hours per day is associated with increased mortality risk[14]. More recent literature on adults describes this relationship without a definitive cut-off, instead showing that each additional hour spent sedentary increases risk, with the time spent being physically active mitigating this risk[15, 16]. Older age did not alter the results[15]. When not only total time, but also features such as frequency, timing and bout duration are included, older adults who have the most sedentary profile have a threefold mortality risk compared to the most active group[17]. Recommendations therefore include breaking up sedentary bouts every 30-60 minutes with some form of activity[15, 16]. Additionally, recent findings suggest

that among adults aged 60 years or older, who accumulate at least eleven hours of sedentary time per day, reducing sedentary time by 30 minutes may lower mortality risk by 10%[18]. These reductions are possibly greater reductions when increasing time in moderate to vigorous physical activity[18]. However, it remains unclear whether such recommendations are feasible or clinically meaningful for older adults in geriatric rehabilitation.

Integration in the treatment program to change behaviour

In this thesis various sensor monitoring technologies were used. Besides the need for accurate measurement, chapters 2, 3 and 5 all indicated that sensor monitoring technology should be integrated into the treatment program to be successful in supporting self-management of older adults in geriatric rehabilitation. In the current studies, this integration was still suboptimal, which may be related to the complexity of the geriatric rehabilitation context, involving complex cases within an interdisciplinary setting. In addition, to ensure usability and effectiveness, a successfully integrated intervention should include tailored behaviour change techniques, such as feedback and self-monitoring (chapter 4)[19]. Taken together, both 1) the content of an intervention, including behaviour change techniques, and 2) the degree of integration into the treatment program, are essential for successful application of sensor monitoring technology to support self-management in geriatric rehabilitation.

Regarding the content, the interventions described in chapters 2 through 5 used sensors that measured various parameters and included mainly the behaviour change techniques feedback and self-monitoring. To ensure that interventions support self-management or enhance behaviour change, additional behaviour change components could be included. There are over 90 behaviour change techniques, and the most frequently included techniques to reduce sedentary behaviour are feedback on behaviour, goal setting, self-monitoring, action planning and adding objects in the environment[19, 20]. Although interventions containing more behaviour change techniques are often reported to be more effective than those only containing some, chapter 4 suggested that the tailored use of techniques might be more important than the number of techniques alone[19]. Therefore, to decide or evaluate which behaviour change techniques should be used in an intervention, or to evaluate whether the selected techniques are appropriate, the COM-B model (Capability, Opportunity, Motivation) is often applied[21]. According to this model, behaviour is dependent on capability (physical and psychological), opportunity (social and physical), and motivation (automatic and reflective). Applying this

model to the findings of this thesis shows that all three components shape the use of sensor monitoring technology in geriatric rehabilitation. For example, the importance of ease of use relates to both capability and opportunity. Integration into the treatment program, and the need for support also reflect opportunity. In addition, inconclusive effects and limited perceived added value may influence motivation. To deepen these insights and tailor the innovation more explicitly to the target group, the Theoretical Domains Framework (TDF) can be used[22]. The TDF comprises fourteen domains that identify cognitive, affective, social, and environmental influences on behaviour. The findings of this thesis can be mapped onto several TDF domains. The outcomes align with knowledge, skills, environmental context and resources, social influences, and beliefs about consequences.

To improve the integration of sensor monitoring technology into the treatment program, several frameworks can be used, each with a different focus. In chapter 3, the CeHRes Roadmap was applied to adapt a sensor monitoring system developed for COPD patients to the geriatric rehabilitation context. This framework guides the development, implementation (including integration) and evaluation of eHealth through five intertwined phases and connecting cycles supported by continuous formative evaluation cycles[23]. Its holistic nature, with focus on development and implementation aligns with the need for early contextualisation and co-creation when adapting an intervention to the geriatric rehabilitation context. This is reflected in this thesis by usability and feasibility challenges that required the iterative co-creation and associated adaptations, such difficulties with the installation process, and integration into the rehabilitation program. In the 2025 updated version of the CeHRes roadmap, it strengthened its focus on behaviour change, implementation and evaluation as iterative processes[24], which corresponds with the described needs in this thesis To clearly identify the factors that influence the implementation of an innovation, the Consolidated Framework For Implementation Research (CFIR) can be used as an additional framework[25]. Unlike the CeHRes roadmap, CFIR does not focus on eHealth specifically, nor on the intervention development. Instead, it focusses on identifying barriers and facilitators that influence implementation within five domains: the innovation, the inner and outer setting, the individuals, and the implementation process[25, 26]. Identified challenges in this thesis such as ease of use, measurement accuracy, and perceived added value (chapters 2, 3, 5) can be primarily fit in the *innovation domain*. In addition, the inconclusive evidence on effectiveness and the absence of clear impact on sedentary behaviour (Chapters 4 and 6) further

relate to this domain, as they influence the perceived strength and value of the innovation. Challenges related to integration into the rehabilitation program reflect the *implementation process*, while the need for support primarily aligns with the *inner setting*. Furthermore, the perceptions of patients and professionals (chapters 2, 3, 5) highlight the role of the *individuals domain*. CFIR thus helps to understand which factors influence the integration of an innovation, and how these factors may be addressed to achieve a better fit with practice. Once these determinants are clear, attention can shift to practical and organizational concepts of using eHealth in healthcare settings. At this stage, the Hybrid Health Care Quality Assessment (HHQA) can be utilized as a practical addition to the CeHRes roadmap to assess organisation fit and readiness[27]. The HHQA emphasizes that the role of the user of an intervention needs to be incorporated into the organizational structure and daily care process. The need for integration in the rehabilitation program that is described in this thesis resonates with this. The model further emphasizes that the technology must be well attuned to the organizational structure and daily care process. Lastly, it highlights that professionals should be deployed in ways that support the intended outcome of care.

Ideally, improving the integration of sensor monitoring technology in geriatric rehabilitation requires a combination of all three models, depending on the stage of innovation readiness. The CeHRes, with its focus on co-creation, could be used for overall guidance, and for pre-implementation context and early integration, as we did in chapter 3. Additionally, the CFIR can be applied to analyse determinants that influence the success of adoption and sustained use. The HHQA can be used to assess and optimize the fit of sensor monitoring technologies within geriatric rehabilitation. Importantly, the distinction between goals and focus areas of different models should be explicitly considered to prevent unclarities and avoid confusion in their application.

Boundaries of eHealth

While the models help to understand which factors influence the use and implementation sensor monitoring technology in geriatric rehabilitation, it is also important to reflect on whether this technology is always the appropriate solution. The use of this technology requires sufficient capability, opportunity and motivation, which may be limited by challenges such as low digital literacy, usability and perceived added value (chapters 2, 3 and 5)[28]. In addition, identified issues related to integration into the geriatric rehabilitation program, the need for support and technical challenges (chapters 2 through 6) indicate

that a good fit with the context is not always achieved. Other challenges, such as usability barriers, fragmented systems, malfunctions, and uncertainty about long-term effects and benefits may further hinder adoption and increase the risk of inequalities[28, 29]. Moreover, the potential for continuity of use during and after rehabilitation raises questions about responsibilities and accountability for interpreting and acting upon data (chapter 3). Taken together, the use of sensor monitoring technology in geriatric rehabilitation should not be considered a one-size-fits-all solution, but instead requires careful consideration of the target population, context and intended outcomes.

Methodological considerations

Regarding the studies presented in this thesis, there are several methodological considerations that require attention. There are three issues that will be discussed here 1) the sample size of the studies, 2) the utilization of co-creation: theory and practice, and 3) the choice of study design.

Sample size

The studies described in chapters 2, 3, 5, and 6 all included fewer than fifty participants. Although the required sample size depends on the specific study aim and method, these relatively small samples may have influenced the robustness and representativeness of the findings. For instance, although chapter 2 did provide a first insight into the potential value of a monitoring bracelet, it is uncertain whether data saturation was sufficiently reached to ensure a representative range of perspectives.

In chapters 3, 5 and 6, the inclusion rates were affected by contextual and organisational factors such as the number of eligible patients, project-related time constraints, and in one case, procedural issues such as unequal randomization due to being part of a larger trial (chapter 6). Additionally, the criteria and process by which patients were deemed eligible may have influenced sample size and introduced selection bias. In the study described in chapter 3, for example, healthcare professionals decided whether patients were fit to participate in the study and use the intervention. Their perspective on the intervention and on the digital literacy of patients may have reduced inclusion rates more than anticipated. Additionally, the way a sensor monitoring technology was introduced to patients may also have influenced participation. In chapter 5, the technology was not presented as optional, but as part of the blended-care treatment program. Only when HCPs or participants identified an obvious reason why the technology was not usable or feasible for the

participant, he or she did not use it. This approach may have increased sample size and reduced selection bias but also limited insight into patient willingness or acceptability.

As a result of the small sample sizes, it remains uncertain to what extent the collected data are representative of the broader geriatric rehabilitation population, thereby limiting the generalizability of the findings. This limitation is further reinforced by the fact that most studies were conducted in a limited number of participating centres and predominantly in the Netherlands (except for chapter 6). Nevertheless, except for chapter 6, it is not expected that substantially larger sample sizes would have led to markedly different outcomes. Instead, the content of the intervention was likely more influential than sample size alone.

Co-creation: theory and practice

To ensure that interventions with sensor monitoring technology fit the broader geriatric rehabilitation context and align with the needs and preferences of its users, it is essential to incorporate stakeholders' perspectives and co-create the intervention with them[24]. For this reason, co-creation was considered a prerequisite in shaping the studies described in this thesis. The importance of this approach is reflected in chapters 2, 3 and 5, with chapter 3 demonstrating the most extensive application through iterative adaptations of the system based on perspectives from multiple stakeholders.

Although the importance of co-creation is widely acknowledged in theory, practical implementation can be challenging. In chapter 3, for example, co-creation was initiated from the first phase of the CeHRes roadmap. However, the initial selection of the intervention had already been made prior to the study, which naturally limited the extent to which certain elements could be tailored. Moreover, it is important to note that effective co-creation requires sufficient time and resources to 1) gain co-creators' perspectives and 2) put points of improvement into concrete adjustments. Additionally, stakeholders may also express diverse or conflicting views or suggest solutions that are not possible within the possibilities, vision, or timeframe of the project in which solutions must be sought. Nonetheless, the study successfully applied co-creation, which resulted in a sensor-based intervention that was more closely aligned with the geriatric rehabilitation context than before.

Similar practical considerations emerged in chapter 5. Based on feedback from healthcare professionals, the sensor technology was adapted during the process. However, additional rounds of co-creation might have allowed the intervention to reach a more optimal fit, particularly regarding further alignment with patient goals and the treatment program. In future studies, allocating more time for iterative co-creation could help maximise the potential of this approach.

Choice of study design

This thesis uses a range of study designs: a systematic review (chapter 4), a qualitative study (chapter 2), two mixed-methods studies (chapters 3 and 5) and a quantitative study (chapter 6). Each methodological approach has its own strengths and contributes to a comprehensive understanding of the use of sensor monitoring technology in geriatric rehabilitation to support self-management and decrease sedentary behaviour.

Both in chapters 3 and 5, a mixed-method design was chosen to enable a broad and multifaceted perspective on the research questions. Nevertheless, the way in which these two studies mixed methods differed. Chapter 3 relied primarily on qualitative data, with quantitative measurements serving to enrich the findings. In contrast, chapter 5 was predominantly quantitative, supplemented by one qualitative component: a focus group with professionals. In this chapter, patient perspectives were gathered quantitatively (through a survey). This approach aligned with its role as a sub-study within the Better@ Home trial, which was designed with a quantitative approach. However, in retrospect, incorporating qualitative data may have provided additional depth regarding the patient's experience with the sensor monitoring technology. This data could have offered richer insights into their perspective on the use of the device, what they perceived as the goal of its use, what they had discussed about the outcomes with the HCP, or if they did not discuss the outcomes at all. Nevertheless, the chosen methods were appropriate within the constraints and objectives of the overarching trial.

Implications and recommendations

The following section describes implications and recommendations for clinical practice and policy, education, and future research based on the results of this thesis. It is important to acknowledge that these three fields are interconnected and together could provide a solid base for the evidence-based use of sensor monitoring technology in geriatric rehabilitation.

Clinical practice and policy

The application of sensor monitoring technology in geriatric rehabilitation has potential for clinical practice to support self-management and reduce sedentary behaviour of older adults, although several challenges remain. Sensor monitoring technology could monitor and support self-management or training by measuring (vital) parameters, activity levels or symptoms, alerting to deviations, and by providing feedback on the parameters[30]. The recommendations for policy and practice below address 1) essential qualities for sensor monitoring technology itself and 2) how to optimise its use in clinical practice.

Before starting to use a sensor monitoring system, it is important to clearly define the aim of its use. This includes determining which rehabilitation goals the sensor should support and what outcomes it must provide for it to be usable. A pre-implementation phase can be valuable for identifying stakeholder needs and ensuring that the chosen sensor aligns with users' needs and preferences. To ensure the sensor fulfils its intended purpose, it is essential to select a device is that is easy to use and measures outcomes with sufficient accuracy.

Given the complexity of the geriatric rehabilitation context, sensor monitoring technology in this setting should be simple, tailored, and blended[31]. Further, an organization-wide implementation strategy should be established, and there should be availability of support for all users when that is needed[31]. It should be acknowledged that a successful application may require adaptations to the technology or workflow, and that such adjustments may take time before becoming usual care. Ultimately, genuine integration into clinical practice is important for successful use of sensor monitoring technology which requires both a clear connection to rehabilitation goals and adoption by the whole team.

Education

To integrate sensor monitoring technology in geriatric rehabilitation, both students learning for a job in rehabilitation and professionals working in rehabilitation first need a clear understanding of eHealth and sensor monitoring technology and their potential applications and challenges. With the fast-pacing changes in digital possibilities, education may even need to go one step further by addressing how to deal with innovations more generally. Training should cover essential eHealth topics to answer questions such as which types of eHealth are available and what eHealth and sensors could be

used for. Furthermore, advanced topics such as methods for implementation and evaluation, including dealing with practical limitations, must be addressed. More specifically, professionals and students in geriatric rehabilitation must understand *for which goals* sensor monitoring technology can be used (for both them and patients), *how* to use this technology to support self-management, and, when needed, *where* to obtain support. Also, they should learn to integrate the technology within existing treatment goals to improve patient care. In addition, some professionals require more in-depth expertise to identify appropriate eHealth solutions. Herewith, they need to understand potential barriers and apply models that guide implementation and evaluation.

Additionally, given the interprofessional collaboration required in geriatric rehabilitation, professionals and students need to learn to address complex issues together. This includes the application of sensor monitoring technology to support shared goals. It is preferable that they learn these collaborative skills while using these technologies as students. This can be facilitated through collaborative assignments across study programmes such as physiotherapy, occupational therapy, nursing, and technical medicine or human technology. For example, students may work together on a geriatric rehabilitation case about a patient who aims to enhance self-management skills and reduce sedentary time. The students collaboratively develop a treatment plan to achieve these goals, incorporating eHealth based on their combined expertise.

Finally, to reduce the sedentary time of patients, both students and professionals should be educated about sedentary behaviour and its associated health risks. They need to understand that risks 1) relate to total sedentary time and to the pattern of sitting time throughout the day, and 2) that these risks exist independently of physical activity. Professionals and students must be equipped with the knowledge and technology to support patients in behaviour change to reduce sedentary behaviour. Finally, they should be educated on the amount of sedentary time and pattern change that is necessary to achieve clinically relevant differences and how to integrate this into the treatment. However, because both are still unclear, further research is required before this can be included in the educational programmes.

Research

This thesis contributes to the understanding of how sensor monitoring technology can be applied to support self-management and address sedentary behaviour in geriatric rehabilitation. As with all research, the knowledge

gained also raises new questions and directions for future studies. A primary implication is the need for sensor monitoring technology that is validated for use in geriatric rehabilitation. Future research is necessary to validate such sensors, ensuring that they measure sufficiently accurate for their intended purpose. Within this context, it should be checked if sensor performance does not differ between inpatient rehabilitation and rehabilitation at home. In addition, future studies should investigate whether advanced techniques, such as deep learning, can improve the sensors' performance within the rehabilitation context in support of self-management[6]. Further development of sensor monitoring technology for geriatric rehabilitation should draw on behaviour change models such as the COM-B and TDF to ensure that intervention components are appropriately tailored[21, 22].

Regarding sedentary behaviour in geriatric rehabilitation, future studies must provide more insight into sedentary time and patterns of patients in this population to identify patients at risk of adverse health outcomes and areas for improvement in their movement behaviour. A good starting point for would be a cross-sectional observational study in which movement behaviour is objectively measured and

associations with risk factors can be identified. While retrieving these insights, there should be aimed for a consensus not only on which sedentary outcomes to include, but also on how these outcomes are operationalised and measured. This consensus should preferably be formalised in a standardised guide to support consistency and comparability across studies. In addition, practice-based research is needed to deepen the understanding of sedentary patterns among patients in geriatric rehabilitation and to explore how these can be modified in daily practice. Again, behaviour change models such as COM-B and TDF should be integrated into these studies to examine individual and contextual determinants of sedentary behaviour. This approach can also help to provide insight into the stakeholder perspectives, including barriers and facilitators for change.

Finally, to further support the integration of sensor monitoring technology for self-management and sedentary behaviour into practice, future research should focus on the development of blended, interdisciplinary interventions through co-creation. Such studies should follow an iterative design, guided by frameworks such as the CeHRes roadmap, and use implementation models

such as CFIR and HHQA to optimize usability, feasibility and effectivity within geriatric rehabilitation practice[26, 27].

Epilogue – a vision for the future in the case of Ms. van Stavenberg

In the second week of rehabilitation, Ms. van Stavenberg is provided with a wearable sensor that continuously tracks her heart rate, sedentary time, physical activity, and oxygen saturation. Through an individualized mobile application, this data is translated into meaningful insights. The application offers tailored education about stroke and recovery, enables progress tracking, provides exercise adapted to her level, and facilitates communication with peers and healthcare professionals.

After the first week of use, she sits together with a therapist to reflect on her experiences. They explore how the technology can best support her in daily life, set personalized activity goals, and select the now appropriate exercises. The application provides regular feedback and prompts her to interrupt prolonged sedentary periods. Additionally, it gives her the opportunity to change her goals and levels by herself. She appreciates being able to practice in outside therapy sessions and feels supported in the choices she makes throughout the day.

For the rehabilitation team, the integration of sensor data offers valuable insights into Ms. van Stavenberg's functioning beyond therapy sessions, thereby supporting them in clinical decision-making, and enabling more personalized care. Based on her progress, the team decides that Ms. van Stavenberg can continue the final phase of her rehabilitation at home.

During the home-based rehabilitation, the application supports Ms. van Stavenberg in practising independently and reaching out to peers or the therapist when needed. Once a week, she evaluates and adjusts her goals in line with her recovery and preferences together with a professional.

After rehabilitation, she continues using the application to support her active lifestyle. It helps her to maintain healthy routines and prevent relapse into sedentary behaviour. She is happy with the enhancement of her rehabilitation by this personalized, blended form of care and with the support and trust the application gave her and will continue to give her.

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SUMMARY

The increase of the ageing population is associated with an increase in age-related declines. These age-related declines can increase the risk of an acute event and adverse outcomes. After such an event, older adults require adequate support to restore their quality of life and, as far as possible, their independence. Geriatric rehabilitation is a multidimensional approach that plays a critical role in helping these older adults restore functional ability and improve functional capability. Its goal is to optimize functional capacity, promote activity, and preserve functional reserve and social participation in older adults with disabling impairments.

One of the key objectives in geriatric rehabilitation is the optimization of self-management. This involves improving patients' ability to manage living with, and increasing their resilience to, condition-related changes in daily life. Optimizing self-management includes the encouragement of patients to engage in physical activity to improve functional performance. However, patients in geriatric rehabilitation seem to spend most of their day sedentary. This is concerning, as prolonged sedentary behaviour is associated with an increased risk of various non-communicable diseases and all-cause mortality. Not only the total sedentary time, but also the pattern in which it is accumulated contributes to these risks. Despite these risks, there is limited knowledge on how to best support older adults in geriatric rehabilitation in reducing sedentary behaviour.

eHealth, including sensor monitoring technology, can play a potential role in filling the needs in geriatric rehabilitation to support self-management and reduce sedentary behaviour. This is especially the case when it delivered as blended care, in which sensor monitoring technology is combined with conventional geriatric rehabilitation. Sensors are generally easy to use, lightweight, and often capable of providing continuous feedback on activity behaviour. However, evidence on the use of sensor monitoring technology in geriatric rehabilitation remains limited. There is a lack of knowledge about stakeholders' perspectives on barriers and facilitators, as well as on the most suitable sedentary outcomes to measure objectively. As a result, the application of sensor monitoring technology in geriatric rehabilitation to support self-management and reduce sedentary behaviour is scarcely implemented and is far from reaching its full potential.

The current thesis describes the findings of the EAGER-2-SEE (EheAlth in

GEriatric Rehabilitation to improve SElf-managEment) study. The overall aim of this thesis is to provide evidence on how sensor monitoring technology can be used to support the self-management of older adults during geriatric rehabilitation. More specifically, this thesis focuses on the use of sensor monitoring technology in relation to reducing sedentary behaviour. Accordingly, the central research question of this thesis is:

How can sensor monitoring technology be applied in geriatric rehabilitation to improve self-management and reduce sedentary behaviour?

Main research findings

Chapter 2 explores the perspectives of healthcare professionals and patients with COPD at high risk for exacerbations on the potential use and value of a sensor-monitoring bracelet. Using focus groups and interviews including six healthcare professionals and five patients participated, insights were gathered into attitudes, wishes, needs, as well as factors that could either support or impede the potential use of a monitoring bracelet. Overall, participants regarded a monitoring bracelet as a potentially beneficial and valuable tool, especially for the support of self-management. They indicated that a monitoring bracelet should detect an exacerbation early by the identification of deviations from an individual's normal (vital) parameters, and to provide feedback to users about these changes. Key facilitators included ease of use and availability of support to help patients use the bracelet and interpret their data. Factors such as costs and the required digital literacy were identified as important considerations for its potential use in practice.

Following the exploration of stakeholder perspectives in chapter 2, **chapter 3** describes de adaption of a system that was originally developed for patients with COPD at home for use by older patients with COPD and their healthcare professionals during inpatient geriatric rehabilitation. Five healthcare professionals and ten patients participated in this mixed-method study. Feasibility, usability, and adherence were evaluated across three iterations using interviews, focus groups and quantitative data from the monitoring system. The system was frequently used and underwent several adaptations throughout the study. Patients particularly valued the insight into their step count, whereas healthcare professionals valued the insight into patients' health status. However, usability and feasibility challenges identified that more time and further adaptations are needed for the system to fit with the geriatric rehabilitation setting. This included the need for the system to be easy to

use from the start, to provide accurate measurements, and to be integrated into the rehabilitation program with adequate support for both patients and healthcare professionals.

In the subsequent chapters, the focus narrows from the role of sensor monitoring technology in supporting self-management during geriatric rehabilitation to the objective measurement and reduction of sedentary behaviour. As feedback on, and self-monitoring of behaviour can influence behaviour, **chapter 4** assess the effectiveness of interventions that use feedback from objective measurements to reduce sedentary behaviour in older adults during post-acute rehabilitation. Eleven studies were included in this systematic review. The included studies varied substantially in terms of content, methodology and sedentary outcomes, and high-quality evidence was limited. Six studies reported a reduction in sedentary behaviour following interventions incorporating objective feedback, whereas five reported no effect. Overall, the evidence remains inconclusive.

To gain further insight into the influence of feedback on sedentary behaviour, **chapter 5** examines the perspectives of patients and healthcare professionals on the usability and feasibility of a sensor monitoring system that provides feedback on sedentary behaviour during both inpatient and home-based geriatric rehabilitation. In this mixed-method study, part of the Better@Home study, patients wore a sensor, could view their data on a platform and discuss these data with a healthcare professional. Data collection included a focus group with healthcare professionals, a survey among patients and quantitative data derived from the monitoring system. In total, twenty-six patients and nine healthcare professionals participated. The monitoring system was perceived as helpful for gaining insight into activity levels and supporting conversations about behaviour. However, overall usability was perceived as limited, due to concerns regarding measurement accuracy, unclear goals and limited perceived added value to the rehabilitation process. Feasibility was considered sufficient, although improvements were needed. Adherence levels were high, and patients were sedentary over 90% of the day across both inpatient and home-based rehabilitation.

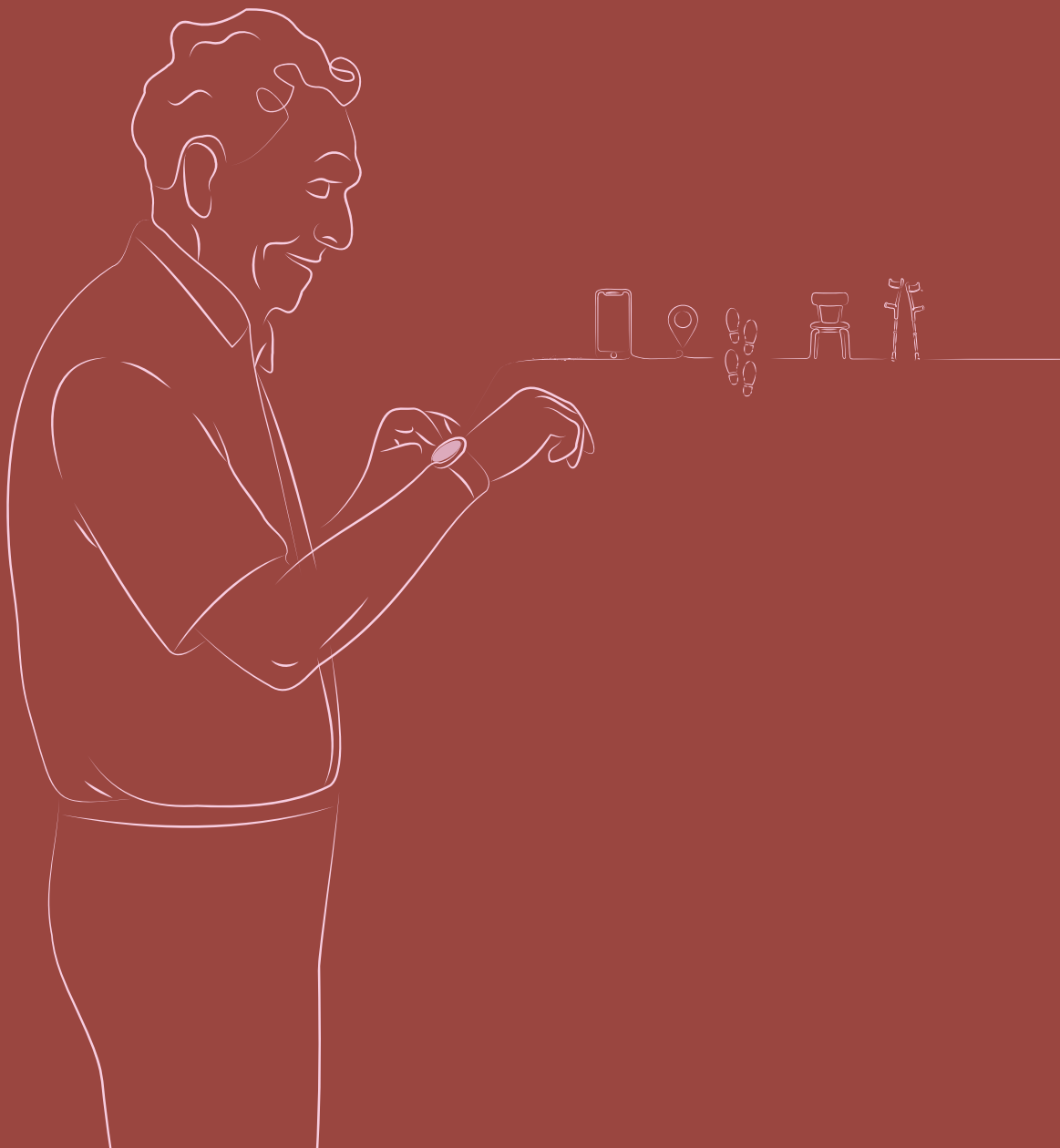
To provide insight into the sedentary behaviour of older adults after an event, **chapter 6** presents an exploratory study examining the influence of NoraHome on sedentary time of older adults with transient ischemic attack (TIA) or minor stroke. The study compares sedentary outcomes between patients receiving

hospital-at-home care using digital monitoring through the NoraHome platform, with those receiving conventional hospitalization. In this quantitative study, part of the NoraHome trial, participants wore a sensor for seven days during the first week after stroke and again after three months. Fifteen participants were allocated to NoraHome group and thirty to the control group. Both groups spent more than 11 hours per day sedentary during the first week after stroke. After three months, both groups sat approximately 10 hours per day. Between-group differences were non-significant at both timepoints. Overall, the study did not provide evidence for a clear influence of NoraHome on the sedentary behaviour of older adults during the acute and subacute phase after stroke.

Conclusion

Based on the findings of this thesis, the main conclusion is that there are various factors to consider when applying sensor monitoring technology in geriatric rehabilitation to support self-management and address sedentary behaviour. It is essential that the technology is easy to use from the start, provides sufficiently accurate and clinically valid measurements, is tailored to rehabilitation goals and supports both patients and professionals. A blended-care approach adds value when the technology is integrated into the rehabilitation program. Furthermore, this work demonstrates that sensors should be validated to use in geriatric rehabilitation, and the application should be guided by an organization-wide strategy that includes a pre-implementation phase to identify needs and ensure alignment with users' preferences. Adaptations to the technology or workflows may be necessary and may take time before becoming embedded in usual care.

Regarding sedentary behaviour, this thesis shows that patients in geriatric rehabilitation spend most of the day sedentary, indicating that sedentary behaviour is an important target for improvement during rehabilitation. At present, the lack of consensus on sedentary behaviour outcomes, goals, measurement approaches, and clinically meaningful change limits the comparability between studies and the ability to translate sensor-derived data into targeted interventions. Further development of sensor monitoring technology for geriatric rehabilitation should be informed by behaviour change models, to ensure that intervention components are appropriately tailored and effective. Overall, this thesis highlights the need for greater insight into sedentary time and patterns in geriatric rehabilitation, as well as for clearer and more standardised guidance to improve comparability and interpretation across studies.



Chapter 8

PhD Portflio

Academic development – PhD trajectory
CRediT table
Bibliography
Academic training and activities

ACADEMIC DEVELOPMENT – PHD TRAJECTORY

In my **first PhD year**, my work focused on the studies described in chapters 3 and 4 of this thesis. I started with writing the study protocol for chapter 3 and establishing a collaboration with the participating rehabilitation center. This strengthened my ability to design mixed-methods research, and navigate interdisciplinary collaboration, communication, and ethical approval procedures. At the same time, I expanded my subject-specific knowledge and knowledge on both quantitative as qualitative research methods, identified a research gap and initiated the development of the study protocol for chapter 4.

During this perioded, I took the role as head of the steering group, chaired meetings, and coordinated the decision-making processes. This experience further developed my organizational and leadership abilities. Once the study started, I strengthened the collaboration with the industry partner, coordinated participant inclusion, and conducted interviews and focus groups, gaining hands-on experience in participatory research and study coordination. I also learned to manage practical challenges, including delays related to the norovirus and COVID-19.

In addition to my research activities, I supervised two POF-projects (Praktijkgericht Onderzoek Fysiotherapie) for physical therapy students at the Hogeschool Leiden, which strengthened my mentoring skills. I presented on the UNC-ZH symposium and contributed as a member of the PhD-committee of the Public Health and Primary Care department. Together with other committee members, I represented PhD candidates in meetings with the department's management team, organized meetings and activities for PhD candidates, and advocated for improvements in organizational processes, further enhancing my professional communication.

In my **second year,** I took primary responsibility for conducting and completing both quantitative and qualitative data collection for the studies presented in chapters 2, 3 and 4. I subsequently analysed the data and drafted the corresponding manuscripts. This included the submission of the manuscript for chapter 2 to a journal. Further, I joined the Better@Home research group, collaborated with another industry partner providing the sensor technology, and designed the mixed-method study described in chapter 5, for which data collection was initiated.

In parallel, I began developing the research protocol for chapter 6 and reached out internationally to set-up a research project. These experiences further strengthened project management skills and my ability to coordinate and communicate across disciplines and settings, also internationally.

Alongside these core activities, I actively participated in a conference, symposia, science days, science meetings, webinars, workshops and more, where I both attended and presented. I also completed several courses aimed at further developing my research and transferable skills.

During my **third year**, I led the submission, revision, and finalization of multiple manuscripts, resulting in two article publications. Data collection for the study described in chapter 5 was completed, and data analysis and manuscript writing were started. At the same time, I developed the study protocol for the study described in chapter 6. A key milestone this year was the establishment of a collaboration with two institutes in Barcelona, Spain. I secured a grant to support this project, which enabled me to approach my research from a new perspective. From December 2024 to June 2025, I lived and worked in Barcelona, where I conducted data collection and initiated data analysis and manuscript writing. This international experience broadened my perspective and further strengthened my ability to take leadership and coordinate research in a multidisciplinary and international context.

In the **final phase of my PhD**, the focus shifted towards finalizing studies, completing data analysis, and preparing manuscripts for publication. I published a preprint of chapter 4 and finalized the articles corresponding to chapters 5 and 6. Through the analysis of the various sensor-based data in these two studies, I further refined my quantitative research skills. During this time, I also served as a peer reviewer for a scientific journal.

Throughout my PhD trajectory, I consistently took the lead in writing, submitting, revising, and finalizing manuscripts. I also completed the mandatory and additional relevant PhD training courses, and regularly presented my work, as well as that of the EAGER research team, at meetings, workshops, and conferences.

Finally, writing chapters 1 and 7, allowed me to integrate my findings and reflect on my work from a broader perspective. This marked the last step in my development into an independent researcher.

CREDIT TABLE

CRediT table for the thesis of Suzanne Debeij

Ch.	Type*	Short Title	Conceptualization	Data Curation	Formal Analysis	Funding Acquisition	Investigation	Methodology	Project Administration	Resources	Software	Supervision	Validation	Visualization	Writing – Original Draft	Writing – Review & Editing	Preregistered	Preprinted	Published with Peer Review
1	Introduction	General Introduction	■				■								■	■	☐	☐	☐
2	PhD project chapter	Sensor Potential Use and Value		■	■		■		■						■	■	☐	☐	☑
3	PhD project chapter	Adapting a Monitoring System	■	■	■		■		■			■		■	■	■	☐	☐	☑
4	PhD project chapter	Systematic Review	■	■	■		■	■	■		■		■			■	☑	☑	☐
5	PhD project chapter	Sensor Usability and Feasibility	■	■	■		■	■	■	■	■			■	■	■	☐	☐	☐
6	PhD project chapter	Comparing Sedentary Behaviour	■	■	■	■	■	■	■	■	■		■	■		■	☐	☐	☐
7	Discussion	General Discussion	■				■								■	■	☐	☐	☐

**PhD project chapters are the direct result of the PhD project of the PhD candidate.*
Some theses also include Collaboration Chapters, to which the PhD candidate has contributed but fall outside the PhD project.

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Publications and submitted manuscripts in this thesis

1. **Suzanne Debeij**, Jiska Aardoom, Miriam Haaksma, Wieteke Stoop, Eléonore van Dam van Isselt, Marise Kasteleyn. The potential use and value of a wearable monitoring bracelet for patients with chronic obstructive pulmonary disease: qualitative study investigating the patient and health care professional perspectives.
    - Chapter 2
    - JMIR Formative Research. 2024 Sep 13;8:e57108. doi: 10.2196/57108.

2. **Suzanne Debeij**, Eléonore van Dam van Isselt, Marise Kasteleyn, Heleen Krabben, Petra Siemonsma, Wilco Achterberg, Miriam Haaksma. Adapting a digital monitoring system for self-management to geriatric COPD rehabilitation: a participatory mixed method study**.**
    - Chapter 3
    - Digital Health. 2025 Jun 9;11:20552076251343782 Doi: https://doi.org/10.1177/20552076251343782

3. **Suzanne Debeij,** Miriam Haaksma, Sander van der Hoeve, Wilco Achterberg, Eléonore van Dam van Isselt. Does objective feedback decrease sedentary behavior in geriatric rehabilitation? A systematic review.
    - Chapter 4
    - MedRxiv 2025.06.24.25327890; doi: https://doi.org/10.1101/2025.06.24.25327890
    - ePoster on EuGMS 2024 – *Objective feedback to decrease sedentary behaviour in geriatric rehabilitation: a systematic review*
    - Poster on SANO wetenschapsdag 2024 - *Vermindert feedback van een objectieve meting sedentair gedrag in de geriatrische revalidatie? Een systematische review*

4. **Suzanne Debeij**, Miriam Haaksma, Margot de Waal, Jolanda van Haastregt, Margriet Pol, Marise Kasteleyn, Eléonore van Dam van Isselt. Usability and feasibility of a wearable sensor providing feedback on sedentary behaviour during inpatient and home-based geriatric rehabilitation.
    - Chapter 5
    - Submitted

5. **Suzanne Debeij**, Marián Muchada, Maria Giné-Garriga, Marta Rubiera, Nicoletta Brunelli, Federica Rizzo, Jules Kraaijkamp, Miriam Haaksma, Wilco Achterberg, Eléonore van Dam van Isselt. Comparing sedentary behaviour after a transient ischemic attack or minor stroke in hospital-at-home and conventional hospitalization pathways: An exploratory trial.
    - Chapter 6
    - Submitted
    - ePoster on ESOC 2026 - *Sedentary time after TIA or minor stroke in Hospital-at-Home vs conventional care*

Other publications

6. Margriet Pol, Eléonore van Dam van Isselt, Arno Doornebosch, Chris Gamble, Marisa Vaz, Wim Groen, Margot de Waal, **Suzanne Debeij,** Francesco Innocenti, Mickaël Hiligsman, Jolanda van Haastregt. Evaluation of outcomes, costs, and feasibility of home-based geriatric rehabilitation after inpatient rehabilitation: study protocol of the “Better@Home” multicentre prospective cohort study with historical control group
    - BMC geriatrics. 2025 Dec;25(1):980. https://doi.org/10.1186/s12877-025-06573-6

ACADEMIC TRAINING AND ACTIVITIES

Completed courses and training

Mandatory

2022 Leiden University Onboarding Programme Inform & Connect
2024 Scientific Conduct for PhD
2024 Basic course for clinical investigators (BROK®)
2024 Basic Methods and Reasoning in Biostatistics

Other courses and training

2023 Academic Outreach
2023 BKO module – werkgroepen begeleiden
2023 Standing up for yourself while keeping good relations (Effective Communication)
2023 Webinar - Mobilise-D Lessons Learned from Patient and Public involvement
2023 Webinar - Zinvol implementeren van zorgtechnologie in de praktijk
2023 Seminar 'Zin in je leven'
2024 Academic writing
2026 Job Orientation
2026 Basiscursus AI-Geletterheid

Conferences, congresses, symposia and trade fairs

2022 SANO wetenschapsdag - De voedingsbodem van de wetenschap
2023 Jaarcongres geriatrische revalidatie - Vernieuwen en veranderen
2023 WeLL symposium
2023 UNC-ZH symposium - Magie van zorgtechnologie
2023 SANO wetenschapsdag
2024 UNC-ZH symposium - Samen voor de ouderenzorg: kennis vanuit onderzoek voor de praktijk
2024 Zorg&ICT beurs
2024 European Geriatric Medicine Society (EuGMS) congress
2025 SANO wetenschapsdag - De kracht van samen
2026 Jaargcongres geriatrische revalidatie – Inspireren en ontmoeten
2026 UNC-ZH symposium – Science with a heart – Samen vooruit, hand in hand naar betere ouderenzorg
2024 Symposium "Een zonnige toekomst voor de geriatrische revalidatie"
2026 European Stroke Organisation Conference (ESOC)

Other activities

2022 Schrijf- en beleidsdagen
2023 PhD day
2024 PhD day
2026 Schrijfdagen

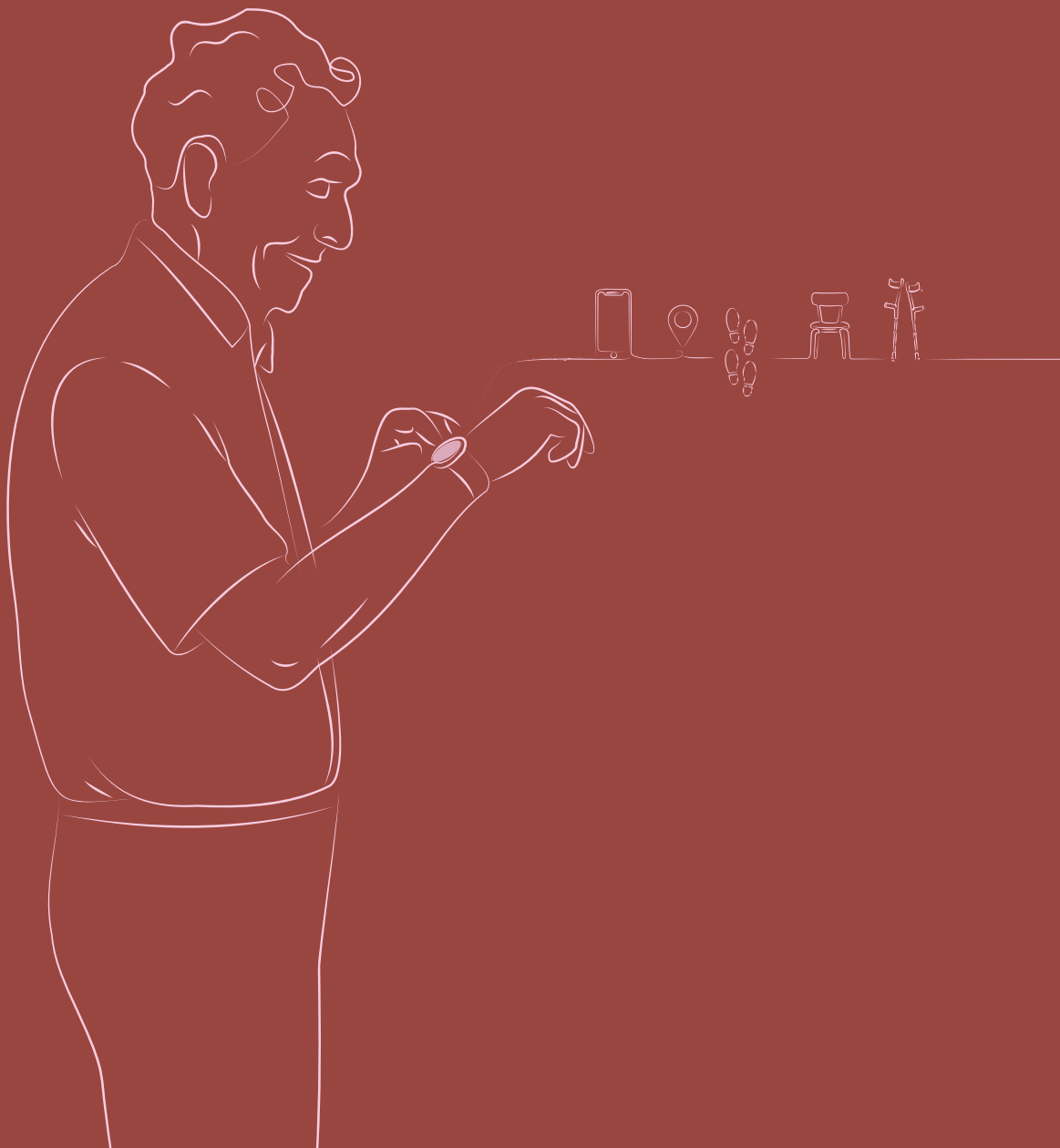
Presentations & workshops

2023 UNC-ZH symposium - Magie van zorgtechnologie - *eHealth in de geriatrische revalidatie*
2023 LCO meeting – *eHealth in geriatric rehabilitation*
2024 Pieter van Foreest meeting – *Aan de slag met Hipper, inzicht in activiteit*
2024 UNC-ZH symposium - Samen voor de ouderenzorg: kennis vanuit onderzoek voor de praktijk - *Couch potatoes in de GR, laten we ze zitten!?*
2024 LCO meetings – *eHealth in geriatric rehabilitation, self-management and sedentary behaviour*
2024 Congres Geriatrische Revalidatiezorg - *Couch potatoes in de GR, laten we ze zitten!?*
2024 Symposium - Een zonnige toekomst voor de geriatrische revalidatie - *Couch potatoes in de GR, laten we ze zitten!?*
2025 LCO meetings – *eHealth in geriatric rehabilitation, self-management and sedentary behaviour*
2025 Presentations Vall d'Hebron neurology department - *NoraHome-SIT*
2025 Landelijke onderwijsdag Geriatrische Revalidatiezorg - *eHealth in de geriatrische revalidatie*
2025 SANO wetenschapsdag – *Inzet van een sensor in de GR om zitgedrag te verminderen, perspectief van revalidanten en professionals*
2026 Presentation Vall d'Hebron neurology department "NoraHome-SIT results"

Teaching activities and student supervision

2022-2023 Supervision of POF project – Een notificatie in plaats van een exacerbatie. *De bruikbaarheid van SmartCOPD bij kwetsbare ouderen met COPD in de geriatrische revalidatie: kwalitatief onderzoek*
2023 Supervision of POF project - Het effect van SmartCOPD in de transitie naar huis bij ouderen met COPD

2023-2024 Teaching working groups: Lijn Samenwerking, Gezondheidsbevordering, en Leiderschap, Medicine Bachelor's year 3



Chapter 9

Appendices

Samenvatting
Dankwoord
Curriculum Vitae

SAMENVATTING

De vergrijzing van de samenleving gaat gepaard met een toename van leeftijd gerelateerde aandoeningen. Deze aandoeningen kunnen elkaar versterken en het risico op plotselinge gezondheidsproblemen en negatieve gevolgen vergroten. Hierna hebben ouderen passende ondersteuning nodig om hun kwaliteit van leven en, voor zover mogelijk, hun zelfstandigheid te herstellen. Geriatrische revalidatie is een multidimensionale aanpak die hierin een cruciale rol speelt. Het ondersteunt ouderen bij het terugwinnen van functionele vaardigheden. Het doel van de revalidatie bij ouderen is het optimaliseren van de functionele capaciteit, het bevorderen van bewegen en sociale participatie, en het behouden van de functionele reserve.

Een belangrijke doelstelling binnen de geriatrische revalidatie is het optimaliseren van zelfmanagement. Dit houdt in dat patiënten beter leren omgaan met veranderingen in het dagelijks leven als gevolg van hun aandoening en actief kunnen omgaan met de uitdagingen die hiermee gepaard gaan. Daarbij hoort ook het stimuleren van beweging en het verminderen van langdurig zitten (sedentair gedrag) om zo het herstel te bevorderen en het functioneren te verbeteren. Ondanks deze focus lijkt het zo te zijn dat patiënten in geriatrische revalidatie het grootste deel van hun dag sedentair doorbrengen. Onder sedentair gedrag wordt al het gedrag verstaan dat tijdens het wakker zijn plaatsvindt in een zittende, liggende of achteroverleunende houding en een laag energieverbruik heeft. Een hoge mate van sedentair gedrag is zorgwekkend, omdat langdurig zitten wordt geassocieerd met een verhoogd risico op verschillende chronische aandoeningen en sterfte door allerlei oorzaken. Niet alleen de totale sedentaire tijd verhoogt dit risico, maar ook hoe dit over de dag is verdeeld. Ondanks deze risico's is er weinig kennis over hoe ouderen binnen de geriatrische revalidatie het beste ondersteund kunnen worden bij het verminderen van sedentair gedrag.

eHealth kan een belangrijke rol spelen binnen geriatrische revalidatie bij het ondersteunen van zelfmanagement en verminderen van sedentair gedrag. eHealth is het gebruik van digitale technologieën om gezondheid en gezondheidszorg te ondersteunen en te verbeteren. eHealth kan vooral ondersteuning bieden als het wordt ingezet als blended care, waarbij de inzet van eHealth wordt gecombineerd met conventionele geriatrische revalidatie. Het gebruik van draagbare sensorsystemen zijn een voorbeeld van de inzet van eHealth. Met sensorsystemen worden systemen bedoeld die een sensor

bevatten die bijvoorbeeld beweging meet, en uit software die deze gegevens uitleest en eventueel terugkoppelt naar revalidanten en zorgprofessionals. Sensoren zijn doorgaans eenvoudig in gebruik, licht van gewicht en vaak in staat om continu feedback te geven op beweeggedrag. Toch is het bewijs voor de inzet van draagbare sensorsystemen in de geriatrische revalidatie nog beperkt. Er is nog onvoldoende kennis over de perspectieven van zorgprofessionals en patiënten op belemmerende en bevorderende factoren die het gebruik van sensorsystemen beïnvloeden, evenals over welke uitkomsten van sedentair gedrag het meest geschikt zijn om objectief te meten. Hierdoor worden sensorsystemen om zelfmanagement te ondersteunen en sedentair gedrag te verminderen in de geriatrische revalidatie nog nauwelijks ingezet, waardoor hun hun potentieel onvoldoende wordt benut.

Dit proefschrift beschrijft de bevindingen van de EAGER-2-SEE (EheAlth in GEriatric Rehabilitation to improve SElf-management) studie. Het algemene doel van dit proefschrift is inzicht geven in hoe sensorsystemen kunnen worden ingezet ter ondersteuning van het zelfmanagement van ouderen tijdens geriatrische revalidatie. Meer specifiek richt dit proefschrift zich op de rol van sensorsystemen bij het verminderen van sedentair gedrag. De centrale onderzoeksvraag van dit proefschrift is als volgt:

Hoe kunnen sensorsystemen worden toegepast binnen de geriatrische revalidatie om zelfmanagement te verbeteren en sedentair gedrag te verminderen?

BELANGRIJKSTE ONDERZOEKSRESULTATEN

Hoofdstuk 2 verkent de perspectieven van zorgprofessionals en patiënten met COPD (Chronische Obstructieve Long Ziekte) op het potentiële gebruik en de waarde van een sensorsysteem: een monitoringsarmband. Met behulp van focusgroepen en interviews, waaraan zes zorgprofessionals en vijf patiënten deelnamen, werden inzichten verkregen over hun houdingen, wensen en behoeften met betrekking tot een monitoringsarmband. Daarnaast werd in kaart gebracht welke factoren het gebruik ervan mogelijk kunnen bevorderen of belemmeren. Over het algemeen beschouwden de deelnemers een monitoringarmband als een potentieel nuttig en waardevol hulpmiddel, met name ter ondersteuning van zelfmanagement. Zij gaven aan dat een armband een longaanval vroegtijdig moet kunnen signaleren door afwijkingen

ten opzichte van normale (vitale) waarden te detecteren en gebruikers hierover feedback te geven. Belangrijke bevorderende factoren waren het gebruiksgemak en de beschikbaarheid van ondersteuning bij het gebruik van de armband en het interpreteren van de gegevens. Kosten en benodigde digitale vaardigheden kwamen naar voren als belangrijke aandachtspunten voor het gebruik in de praktijk.

Voortbouwend op de verkenning van de perspectieven van zorgprofessionals en patiënten in hoofdstuk 2, beschrijft **hoofdstuk 3** de aanpassing van een sensorsysteem. Dit sensorsysteem werd oorspronkelijk ontwikkeld voor patiënten met COPD om het zelfmanagement in de thuissituatie te ondersteunen en bestond uit een digitaal longaanval actieplan en een activity coach. Hoofdstuk 3 beschrijft aanpassingen voor het gebruik binnen de geriatrische revalidatie, voor wel revalidanten met COPD en als hun zorgprofessionals. Vijf zorgprofessionals en tien patiënten namen deel aan deze mixed-methods studie en maakten gebruik van het sensorsysteem. Over drie iteraties werden de haalbaarheid, bruikbaarheid en het gebruik van het sensorsysteem geëvalueerd door middel van interviews, focusgroepen en kwantitatieve gegevens uit het sensorsysteem. Het sensorsysteem werd gedurende het onderzoek meerdere keren aangepast en werd frequent gebruikt. Patiënten waardeerden vooral het inzicht in hun aantal stappen, terwijl zorgprofessionals met name het inzicht in de gezondheidstoestand van de patiënten waardeerden. Tegelijkertijd lieten knelpunten in de bruikbaarheid en haalbaarheid zien dat verdere aanpassingen en meer tijd nodig zijn om het systeem goed te laten aansluiten bij de geriatrische revalidatiepraktijk. Hierbij moet onder andere gedacht worden aan het belang van een systeem dat vanaf het begin eenvoudig te gebruiken is, betrouwbare metingen levert en goed wordt geïntegreerd in de behandeling. Ook moet er voldoende ondersteuning voor zowel patiënten als zorgprofessionals zijn in het gebruik van een sensorsysteem.

In de daaropvolgende hoofdstukken verschuift de focus van de rol van sensorsystemen bij het ondersteunen van zelfmanagement tijdens geriatrische revalidatie naar het objectief meten en verminderen van sedentair gedrag. Omdat feedback op en zelfmonitoring van gedrag het gedrag kan beïnvloeden, wordt in **hoofdstuk 4** de rol van feedback op sedentair gedrag belicht. Het hoofdstuk presenteert een systematische review waarin de effectiviteit van interventies wordt beoordeeld die gebruikmaken van feedback om sedentair gedrag bij ouderen tijdens revalidatie te verminderen. De elf geïncludeerde

studies verschilden sterk in inhoud, methode en uitkomstmaten van sedentair gedrag, en er ontbrak bewijs van hoge kwaliteit. Zes studies rapporteerden een vermindering van sedentair gedrag na interventies met objectieve feedback, terwijl vijf geen effect rapporteerden. Het totale bewijs over het effect van feedback op sedentair gedrag tijdens geriatrische revalidatie blijft onduidelijk.

Om meer inzicht te krijgen in de invloed van feedback op sedentair gedrag beschrijft **hoofdstuk 5** de perspectieven van revalidanten en zorgprofessionals op de bruikbaarheid en haalbaarheid van een sensorsysteem dat feedback geeft over sedentair gedrag tijdens zowel klinische als ambulante geriatrische revalidatie. In deze mixed-methods studie, onderdeel van de studie 'Thuis als het kan' droegen revalidanten een sensor, konden zij hun gegevens bekijken op een platform en deze bespreken met een zorgprofessional. De dataverzameling bestond uit een focusgroep met zorgprofessionals, een vragenlijst voor de revalidanten en kwantitatieve gegevens uit het sensorsysteem. Zesentwintig patiënten en negen zorgprofessionals namen deel. Het sensorsysteem werd als waardevol ervaren voor het verkrijgen van inzicht in hoeveel revalidanten bewegen, de verdeling daarvan over de dag en ter ondersteuning van gesprekken over beweeggedrag. De bruikbaarheid werd echter beoordeeld als beperkt, vanwege zorgen over meetnauwkeurigheid, onduidelijke doelen, en een beperkt ervaren meerwaarde voor het revalidatieproces. De haalbaarheid werd als voldoende beschouwd, hoewel praktische verbeteringen nodig waren. Het systeem werd veel gedragen, en revalidanten brachten meer dan 90% van de dag sedentair door, zowel in de klinische als in de ambulante fase.

Om een beeld te geven van het sedentair gedrag van ouderen in de eerste week na een acute gebeurtenis, presenteert **hoofdstuk 6** een exploratieve studie naar de invloed van een programma waarin ziekenhuiszorg thuis wordt aangeboden met digitale monitoring via het NoraHome-platform (NoraHome) op het sedentaire gedrag van ouderen met een TIA (Transient Ischemic Attack) of een lichte beroerte. In deze studie worden sedentaire uitkomsten vergeleken tussen patiënten die deelnamen aan NoraHome met degenen die reguliere behandeling in het ziekenhuis ondergingen. In deze kwantitatieve studie, onderdeel van het NoraHome onderzoek, droegen deelnemers gedurende de eerste week na de TIA of beroerte voor een periode van zeven dagen achter elkaar een sensor en opnieuw na drie maanden. Vijftien deelnemers werden toegewezen aan NoraHome-groep en dertig aan de controlegroep. Beide groepen waren in de eerste week meer dan elf uur per dag sedentair. Na drie maanden was men in beide groepen ongeveer 10 uur per dag sedentair.

Er werden op beide meetmomenten geen significante verschillen tussen de groepen gevonden. Deze studie bood geen bewijs voor een duidelijke invloed van NoraHome op het sedentair gedrag van ouderen in de acute en subacute fase na een TIA of beroerte.

CONCLUSIE

Op basis van de bevindingen in dit proefschrift kan worden geconcludeerd dat er verschillende factoren van belang zijn bij de toepassing van sensorsystemen in de geriatrische revalidatie ter ondersteuning van zelfmanagement en het verminderen van sedentair gedrag. Het is essentieel dat de technologie vanaf het begin eenvoudig te gebruiken is, dat de sensor voldoende nauwkeurige en klinisch relevante metingen levert, en dat deze aansluit bij de revalidatiedoelen en zowel patiënten als professionals ondersteunt. Een blended-care aanpak voegt waarde toe als de technologie wordt geïntegreerd in het revalidatieprogramma. Daarnaast laat dit proefschrift zien dat sensoren gevalideerd moeten zijn voor gebruik binnen geriatrische revalidatie. Implementatie moet worden ondersteund door een organisatie-brede implementatiestrategie met daarin een voorbereidende fase om de behoeften van belanghebbenden in kaart te brengen en afstemming met gebruikers te realiseren. Aanpassingen aan de technologie of in de werkprocessen kunnen daarbij noodzakelijk zijn en het kost tijd voordat toepassingen zijn ingebed in de zorg.

Met betrekking tot sedentair gedrag wijzen de bevindingen erop dat revalidanten in de geriatrische revalidatie een groot deel van de dag zittend doorbrengen, wat benadrukt dat sedentair gedrag een meer aandacht verdient tijdens het revalidatietraject. Op dit moment beperkt het gebrek aan consensus over passende sedentaire uitkomstmaten, doelen meetmethoden en klinisch relevante veranderingen de vergelijkbaarheid van studies en de vertaling van data van een sensorsysteem naar gerichte interventies. Om ervoor te zorgen dat interventiecomponenten passend en effectief worden afgestemd zou verdere ontwikkeling van sensorsystemen voor geriatrische revalidatie moeten worden gebaseerd op gedragsveranderingsmodellen. Al met al benadrukt dit proefschrift de noodzaak van meer inzicht in de duur en patronen van sedentair gedrag in de geriatrische rehabilitatie. Daarnaast benadrukt het de noodzaak voor duidelijkere en meer gestandaardiseerde richtlijnen rondom sedentair gedrag om vergelijkbaarheid en interpretatie van onderzoek te verbeteren.

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CURRICULUM VITAE

Suzanne Maria Debeij was born in Wateringen, the Netherlands, on April 24, 1997. She completed her secondary education at ISW Gasthuislaan in 's-Gravenzande, graduating in 2015. In the same year, she began studying Human Movement Sciences at Vrije Universiteit Amsterdam (VU), earning her bachelor's degree in 2018. Her bachelor's thesis investigated the role of strength training in anorexia nervosa recovery, while her graduation project examined how concern and trust influence the execution and estimation of two-step tasks in older adults. During her bachelor's studies, she was employed at Aethon Zorg in Den Haag, where she provided personal care at level 2 and medical care at level 3.

In 2019, she started a master's degree in Vitality and Ageing at Leiden University Medical Center, which she completed in 2020. During this year, she was the Public Relations (PR) member of the year representatives of the master, and she was a member of the education committee (OLC). Her master's thesis examined the impact of the COVID-19 pandemic and the preventive restrictions on social participation and the daily functioning of Dutch older adults. After graduating, she started working at Frankelandgroep, where she served as a quality policy officer.

Suzanne continued her academic career in 2022 by joining the Public Health and Primary Care department as a PhD student. Her research focused on the use of eHealth in geriatric rehabilitation to support self-management and reduce sedentary behaviour. While most of the studies she carried out during her PhD were conducted in the Netherlands, she moved to Barcelona, Spain, from December 2024 until June 2025 to conduct a study at the Vall d'Hebron University Hospital. During her time as a PhD student, she followed both courses to increase her academic and digital skills and attended congresses and science days. Besides, she was also an active member of the department's PhD committee, a lecturer, and a student-supervisor. Additionally, she gave workshops and presentations to healthcare professionals and students. She currently at the beginning of the next phase of her career.

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