



Aalborg Universitet

AALBORG UNIVERSITY  
DENMARK

## Development of an individualized asynchronous sensor-based telerehabilitation program for patients undergoing total knee replacement

*Participatory design*

Naeemabadi, MReza; Søndergaard, Jesper Hessellund; Klastrup, Anita; Schlüsen, Anne Philbert; Lauritsen, Rikke Emilie Kildahl; Hansen, John; Madsen, Niels Kragh; Simonsen, Ole; Andersen, Ole Kæseler; Kim, Katherine K; Dinesen, Birthe

*Published in:*  
Health Informatics Journal

*DOI (link to publication from Publisher):*  
[10.1177/1460458220909779](https://doi.org/10.1177/1460458220909779)

*Creative Commons License*  
CC BY-NC 4.0

*Publication date:*  
2020

*Document Version*  
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

*Citation for published version (APA):*

Naeemabadi, MR., Søndergaard, J. H., Klastrup, A., Schlüsen, A. P., Lauritsen, R. E. K., Hansen, J., Madsen, N. K., Simonsen, O., Andersen, O. K., Kim, K. K., & Dinesen, B. (2020). Development of an individualized asynchronous sensor-based telerehabilitation program for patients undergoing total knee replacement: Participatory design. *Health Informatics Journal*, 26(4), 2492-2511. <https://doi.org/10.1177/1460458220909779>

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -



# Development of an individualized asynchronous sensor-based telerehabilitation program for patients undergoing total knee replacement: Participatory design

Health Informatics Journal  
2020, Vol. 26(4) 2492–2511  
© The Author(s) 2020  
Article reuse guidelines:  
sagepub.com/journals-permissions  
DOI: 10.1177/1460458220909779  
journals.sagepub.com/home/jhi



**MR**eza Naeemabadi ,  
**J**esper Hesselund Søndergaard, **A**nita Klastrup,  
**A**nne Philbert Schlüsen, **R**ikke Emilie Kildahl Lauritsen  
**a**nd **J**ohn Hansen  
Aalborg University, Denmark

**N**iels Kragh Madsen  
**O**le Simonsen  
Aalborg University Hospital, Denmark

**O**le Kæseler Andersen  
Aalborg University, Denmark

**K**atherine K Kim   
University of California, Davis, USA

**B**irthe Dinesen  
Aalborg University, Denmark

## Abstract

Telerehabilitation programs can be employed to establish communication between patients and healthcare professionals and empower patients performing their training remotely. This study aimed to identify patients'

## Corresponding author:

MReza Naeemabadi, Laboratory for Welfare Technologies—Telehealth & Telerehabilitation, SMI®, Department of Health Science and Technology, Aalborg University, 9220 Aalborg, Denmark.  
Email: reza@hst.aau.dk



Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).

requirements after a total knee replacement following a self-training rehabilitation program, leading to the design and development of a telerehabilitation program that can meet the stakeholders' actual needs. System design, development, and testing were conducted in five iterations based on a participatory design approach. Data collection was performed using interviews, observations, prototyping, and questionnaires. It was found that the main barriers facing the existing rehabilitation program were a lack of clear communication, lack of relevant information, and healthcare professional's feedback. The participants emphasized the main themes of communication, information, training, and motivation in the process of design and development. In using the telerehabilitation program, the patients reported a high level of user-friendliness, flexibility, and a sense of security. This study has identified obstacles in the current rehabilitation program and revealed the potential effectiveness of using asynchronous communication and sensor-based technologies by employing participatory design and development. A higher level of portability and flexibility were observed. However, future studies and development are required to investigate the overall usability and reliability of the telerehabilitation program.

### Keywords

participatory design and development, sensor-based technologies, telerehabilitation, total knee replacement

### Introduction

Studies have shown that postoperative physical rehabilitation programs had a significant influence on health recovery.<sup>1</sup> Therefore, a wide variety of rehabilitation programs are being advised to treat postoperative recovering patients. Accordingly, self-training approaches have been highly recommended for patients recovering from knee surgery.<sup>2</sup> Lee et al.<sup>3</sup> showed that a tailor-made exercise program has a significant positive impact on patients' adherence and health recovery among senior patients with knee osteoarthritis (KOA). Moreover, it has also been shown that the therapist-patient relationship has a positive influence on the observed clinical outcomes.<sup>4</sup> Baker et al.<sup>5</sup> reported that an in-home training program has a considerable impact on KOA and can lead to substantial improvements in patients' quality of life.

A telerehabilitation program (TRP) utilizes computers, information, and communication technologies to provide rehabilitation services at a distance. A proper telephysical rehabilitation program enables the healthcare sector to introduce a higher quality of clinical services and allows rural communities to enhance accessibility to the healthcare system.<sup>6-8</sup> Previous studies have indicated that the majority of the patients were satisfied and felt more confident due to the TeleHomeCare solutions provided.<sup>9,10</sup>

As an in-home rehabilitation solution, real-time audio or video communication has been utilized. The efficacy of these solutions on patients' functional performance,<sup>11-13</sup> patients' and physiotherapists' satisfaction,<sup>14,15</sup> and system costs<sup>16-18</sup> has been investigated and has shown positive results.

This study sought to develop a TRP with higher degrees of portability and no dependency on real-time video conference communications. It also sought to satisfy users' requirements by providing a tailored TRP to patients' specific needs. Consequently, it is hypothesized that the rehabilitation can be facilitated by a combination of asynchronous communication, sensor-based technologies (utilizing sensors to measure clinical parameters),<sup>19,20</sup> and on-demand synchronized, locally stored information services with the TRP. The target group in this study are patients who have undergone a total knee replacement (TKR).

It should be mentioned that the integration of telecommunication and technologies in healthcare services is deemed to be challenging and has had high failure rates.<sup>21,22</sup> Lack of a clear

understanding of the clinical and practical challenges, as well as specific requirements, had been the factors behind a lower success rate of introduced solutions.<sup>23</sup> Kushniruk and Nøhr<sup>24</sup> showed that participatory development improves the chance of the acceptability of a rehabilitation program because it assembles user input and involves users in the rehabilitation development procedure. In addition, the cost and resource efficiency of this approach were also shown.<sup>25</sup> Although this method increases the complexity of development, it enables the developers to identify the actual requirements,<sup>26</sup> understand the barriers,<sup>27</sup> and lead to a higher end-user involvement<sup>28</sup> and long-term sustainability.<sup>29</sup> As a result, participatory design (PD) and development were utilized in several studies implementing telemedicine and e-health solutions.<sup>30–32</sup> In this study, we decided to use the PD method in developing our TRP.<sup>24,33</sup>

## Materials and methods

### *Participants and the recruitment process*

The project participants were divided into two groups of patients, health professionals (two physiotherapists, a nurse, and an orthopedic surgeon), three researchers, four student assistants, and two software developers.

All patients were identified based on criteria by a healthcare professional at Aalborg University Hospital. A letter of invitation to participate in this study (containing project details and workshop schedules) was sent to all patients. The patients could then express their willingness to participate by informing the project director using the contact information provided in the invitation letter.

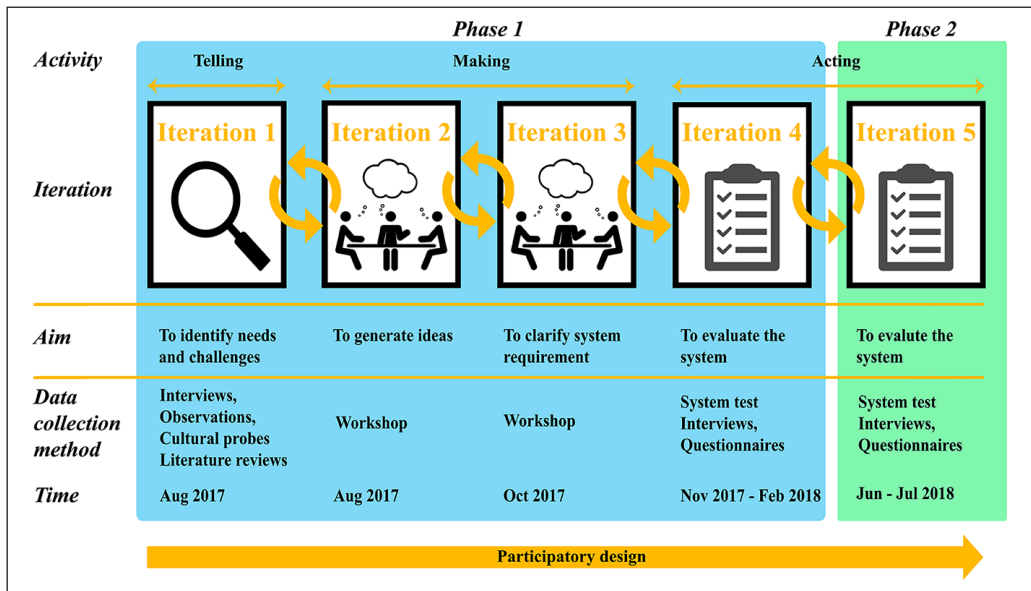
The first group of patients was selected from the patients who had already completed their regular rehabilitation program. They were actively involved in the system developments and preliminary testing (first phase, details in section “Theoretical framework”). The second group of patients was recruited prior to undergoing their knee surgery to test the TRP system for a period of 2 weeks (in phase two). Therefore, they were able to use the TRP after the surgery. This second group of patients did not participate in the system development process, and they participated only in the second phase of the study.

All patients recruited in the study were based on the following inclusion criteria:

- Had or planned to have a primary TKR;
- Ability to understand and accept the trial procedure (evaluated by a healthcare professional);
- Ability to participate in teamwork (assessed by a healthcare professional);
- Resident in municipalities around Aalborg, Denmark;
- Discharged or being discharged for a regular rehabilitation treatment program;
- No other conflicting disorders (evaluated by a healthcare professional).

### *Theoretical framework*

Self-determination theory (SDT) was used as a theoretical starting point to increase the effectiveness of behavior change interventions for patients after knee surgery. SDT offers a framework for understanding the role of individualization in motivation. The theory highlights how the fulfillment of basic needs such as autonomy, relatedness, and competence are essential for initiating and maintaining changes in lifestyle and health behavior over time.<sup>34</sup>



**Figure 1.** Study design. The study is divided into two phases and five iterations. The aims, data collection methods, and time for each iteration are shown in the figure.

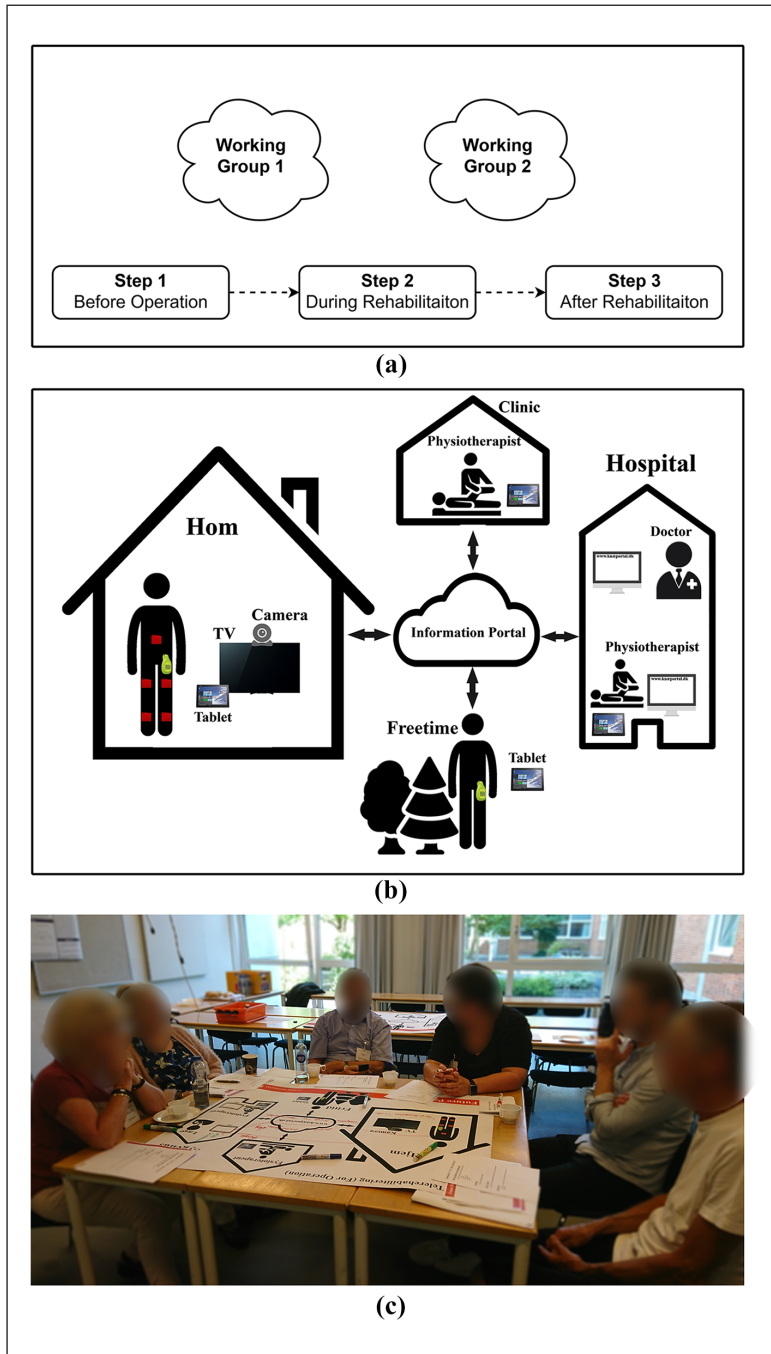
### Study design and data collection

The design and development of the TRP were conducted based on the PD<sup>33,35</sup> in two phases and five iterations, as shown in Figure 1. Based on the previous studies, the iterations can be divided into idea generation (telling), development (making), and test and evaluation (acting) activities.<sup>33,36</sup> Further details about each iteration are clarified in Figure 1.

**Iteration 1: fieldwork data collection.** This iteration sought to identify the needs and challenges of the self-training program. Initially, a review of the literature was conducted in order to investigate the previous relevant studies. This was followed by a semi-structured interview<sup>37</sup> and participant observation<sup>38</sup> at participants’ home. The interview focused on identifying patients’ unresolved needs and challenges posed by the patients’ experiences with the current self-training rehabilitation. Finally, the patients were asked to provide relevant cultural probes<sup>39,40</sup> using text messages, emails, or photos within 2 weeks after the interview.

Interviews were tape recorded, and observational notes were documented at the meeting. The interviews stopped when an indication of data saturation was observed. The interviews were transcribed by J.H.S. and A.K.

**Iteration 2: first workshop.** The primary objective of the first workshop was to generate relevant ideas and draw preliminary paper prototypes, which lasted 2.5h. Initially, a common ground<sup>33</sup> between the participants was established by the workshop organizer. The participants were divided into two mixed working groups comprising healthcare professionals, patients, researchers, and developers. The workshop was organized in three steps, each of which was involved with identifying the relevant ideas and solutions in three time periods (Figure 2(a)). Pre-printed posters (see Figure 2(b)) were laid on each table showing four possible sites (home, physiotherapy clinic,

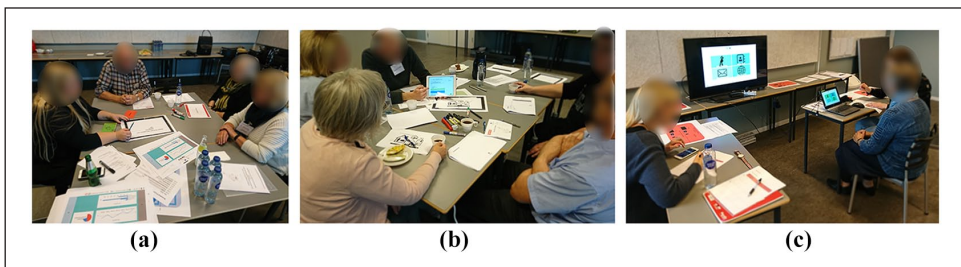


**Figure 2.** Patient workshop: (a) in the first workshop, participants were organized into two mixed working groups following three steps to generate ideas that could resolve the identified needs, (b) participants were asked to draw and write down their ideas on the given pre-printed sheets showing the possible locations where they might utilize the telerehabilitation system, and (c) the working group was sitting behind a roundtable and generated ideas corresponding to each step.

**Table 1.** Description of the second workshop process.

	Working group 1	Working group 2	Working group 3
<b>PARTICIPANTS</b>	<ul style="list-style-type: none"> <li>• A facilitator</li> <li>• Two student assistants</li> <li>• All attended patients</li> </ul>	<ul style="list-style-type: none"> <li>• A facilitator</li> <li>• Two student assistants</li> <li>• A developer</li> <li>• An orthopedic surgeon</li> <li>• A physiotherapist</li> <li>• A head nurse</li> </ul>	<ul style="list-style-type: none"> <li>• Two student assistants                             <ul style="list-style-type: none"> <li>○ Instructor</li> <li>○ Observer</li> </ul> </li> <li>• A developer</li> <li>• A patient/health professional</li> </ul>
<b>AIM</b>	To gain insight into the needs of users	To design the TRP from an organizational context	To evaluate the user-friendliness (usability) of the TRP
<b>METHODS</b>	Focus group discussion, paper prototyping, and drawing	Focus group discussion	Usability test Observation Time spent on the tasks
<b>TOPICS</b>	<ul style="list-style-type: none"> <li>• GUI design</li> <li>• Contents of the rehabilitation program</li> <li>• Information</li> </ul>	<ul style="list-style-type: none"> <li>• Rehabilitation program in the TRP</li> <li>• Communication</li> <li>• Reports and intervention</li> </ul>	User-friendliness of <ul style="list-style-type: none"> <li>• GUI</li> <li>• Sensors</li> </ul>

TRP: telerehabilitation program; GUI: graphical user interface.



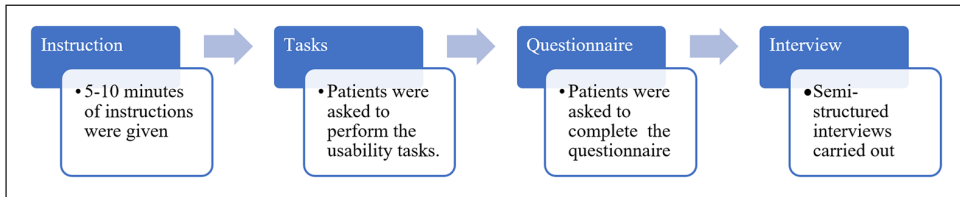
**Figure 3.** Participants were divided into three working groups: (a) working group one carried out brainstorming and prototyping, (b) the second working group investigated the clinical responsibilities for the TRP, and (c) the third working group carried out the first system test.

hospital, and outside) where the patient may need to have access to the rehabilitation program and relevant information (see Figure 2(c)).

The group facilitators (J.H., B.D.) conducted each step of the workshop based on predefined topics and questions. They emphasized on training, communication, information, motivation, transportation, and physical activities. The prototype of TRP has been developed based on the obtained data.

*Iteration 3: second workshop.* The second workshop aimed to qualify and clarify the ideas for the development of TRP. The workshop was organized into three parallel and independent working groups (described in Table 1 and Figure 3) and lasted 2.5 h. All participants in the previous workshop were invited to the second workshop.

The first working group (consisting of the patients, two researchers, and a facilitator) sought to collect insight into the user’s needs and system requirements. Brainstorming, paper prototypes, drawing an idea, graphical user interface (GUI) design,<sup>41,42</sup> and guided discussion



**Figure 4.** The preliminary system test was conducted in the fourth iteration in order to investigate the user-friendliness of the system at the patient's home.

methods regarding the technical restrictions were all used in order to illuminate the patients' needs (see Table 1).

A focus group interview<sup>43</sup> was carried out by three healthcare professionals, a developer, and a facilitator in order to develop the ideas on the healthcare sector, clinical responsibilities, and relevant patient-reported outcomes (PRO) during the rehabilitation period. In each phase, the translation of services and healthcare professional supervision into an electronic system was discussed.

In the last group, two student assistants and a developer asked each of the participants (patients and healthcare professionals) to perform five predefined tasks in order to test the developed prototype. The prototype consisted of two wearable sensors and a Microsoft Windows 10 tablet, customized running project-developed software. During the test, one of the researchers was responsible for instructing users and helping them if they encountered any difficulties while completing the tasks. The second researcher collected the verbal and non-verbal responses of patients and the elapsed time for each task.

*Iteration 4: preliminary testing TRP at the patient's home (iteration 1).* The main aim of this iteration was to acquire patients' feedback by testing the TRP. Two researchers visited each patient's home. One of the researchers was responsible for instructing the patient and actively engaging with them. The second researcher collected the observational data. The program was evaluated in four steps (see Figure 4). Initially, the patient was instructed on how to use the telerehabilitation program and monitored in several tasks in order to assess the user-friendliness of the TRP. While the patients were completing the tasks, the verbal and non-verbal observations were collected. In the next step, the patients were asked to complete a Likert-type scale questionnaire for evaluating the user-friendliness of TRP. Finally, a semi-structured interview was conducted in order to investigate the patients' experience and satisfaction with the technology and presented TRP.

*Iteration 5: testing TRP at the patient's home (second phase).* The primary objective of the second home test was to investigate the preliminary user-friendliness of the revised TRP (further technical details on the TRP are provided in Naeemabadi et al.<sup>44</sup>), and users' experiences for the more extended period are given by including those users who did not participate in the development process. The identical data collection methods were reused from the previous iteration.

The patients were identified and recruited before undergoing knee surgery. Two researchers met the patients prior to the operation at the patients' homes and provided them with the TRP and the relevant instructions. Patients were asked to use the TRP for 2 weeks, and this visit was followed up by a second home visit (after week 2) scheduled in two steps. In the first step, a semi-structured interview was conducted in order to acquire patients' experience in the rehabilitation process. In the second step, patients were asked to fill out a questionnaire (employed in the previous iteration).



**Table 2.** Demographic data of participants.

Group	Population	Gender	Civil status	Had earlier TKR
<b>First group (iterations 1–4)</b>	8 (4 females)	71.71 ± 7.91	Three living alone	1
<b>Second group (iteration 5)</b>	4 (2 females)	69.75 ± 1.71	One living alone	0

TKR: total knee replacement.

### Data analysis

All interviews and observations were transcribed. The data from interviews, observations, documents, and probes were analyzed inspired by Kvale and Brinkmann<sup>45</sup> using NVivo 11.0 (QRS International, Melbourne, Australia) in the same process in the following steps:

1. The collected data in the first iteration was reviewed and processed to extract the key codes.
2. The keywords were discussed to ensure intersubjectivity between the authors.
3. The main themes were identified based on the coded data in the NVivo.
4. The collected data in each iteration were processed and categorized based on the identified themes.

### Results

Eight patients were identified and assigned in the first group. Table 2 represents the demographic data of the users.

Five of the eight patients in the first group participated in all five iterations. One of the patients left the study after the first iteration (due to personal reasons), one more patient after the second iteration (due to a medical condition), and a third patient left the study after the third iteration (due to lack of interest). All four patients in the second group completed the second phase of the study. Figure 5 shows the graphical presentation of the participant in the study.

The collected qualitative and quantitative data in each iteration individually are presented in the following sections.

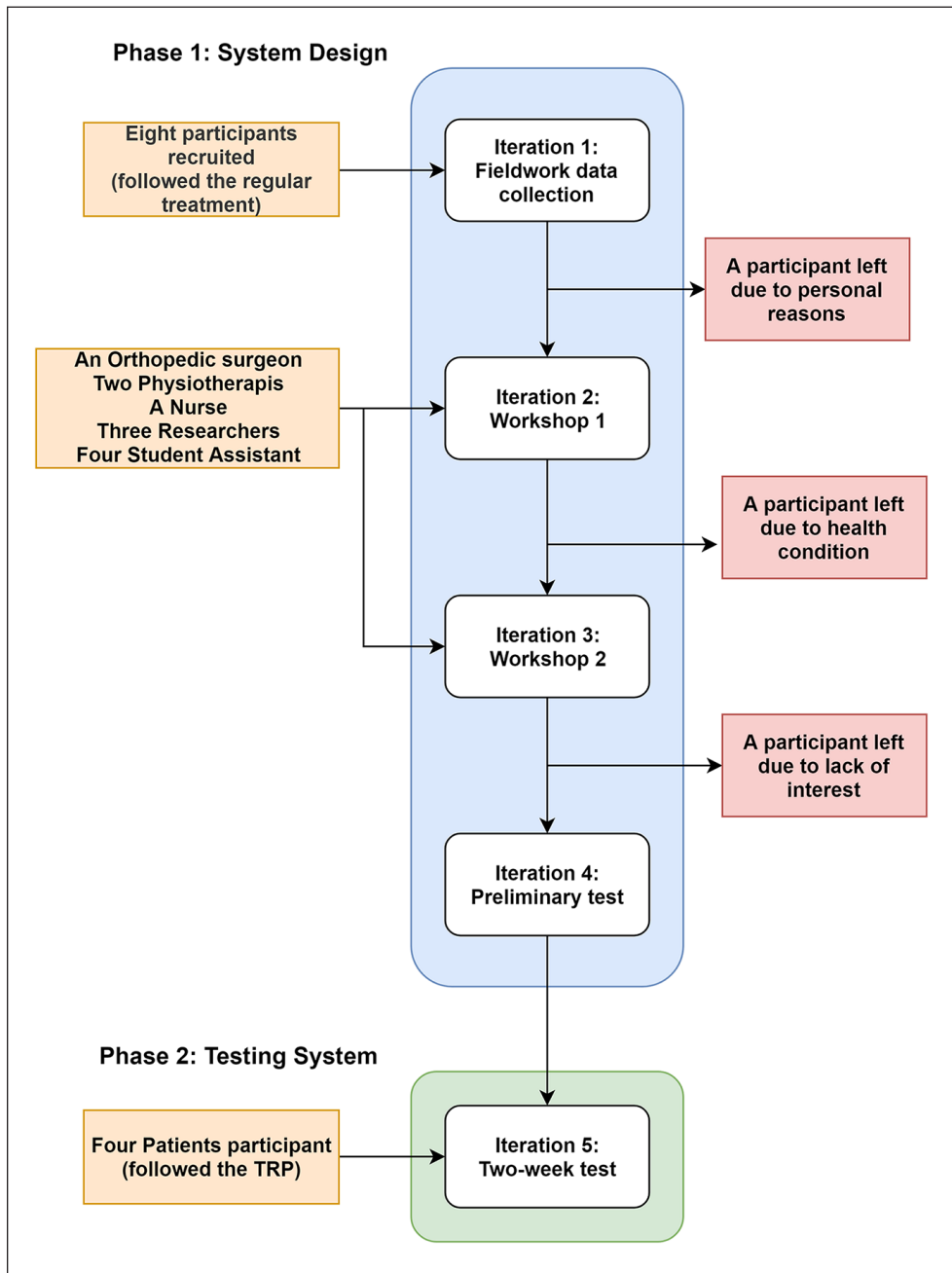
#### Iteration 1: fieldwork data collection

The identified requirements for the TRP were (1) lack of a transparent communication platform, (2) lack of a resource to provide the relevant information, and (3) lack of a healthcare professional's intervention during home-rehabilitation. Accordingly, the collected data were categorized into four main themes, addressing the challenges and needs observed in the regular self-training program. Table 3 shows the themes and corresponding participant statements collected during the interviews.

#### Iteration 2: first workshop

The preliminary ideas were generated in the first workshop in order to overcome the identified challenges; however, some of the ideas might not be feasible to implement due to limitations in the available technologies.<sup>46</sup> The ideas generated in the workshop were grouped into the five themes (defined in the previous iteration) and are shown in Table 4.

The participants believed that users' motivations might be improved by healthcare professionals' feedback and patients' reports. Moreover, it was suggested that a remote communication



**Figure 5.** Graphical presentation of the participants in the study.

platform is established. Also, it was believed that the TRP should offer relevant visual information and instructions for the patients as well as live training (with visual instructions and feedbacks).

Based on users' feedback from the first workshop, the prototype of the software was developed. The TRP was developed for a 10-in Microsoft Windows 10 Tablet and was compatible with touch

**Table 3.** Identified themes during data collection and corresponding patients' exemplary statements.

Themes	Findings	Statements
Communication	<ul style="list-style-type: none"> <li>• Long-distance transportation might require establishing an in-person visit for those patients residing in remote areas.</li> <li>• Patients had difficulties finding the responsible healthcare professional after the operation.</li> </ul>	<p>"I was referred to different departments."                      "I had trouble getting in touch with my contact person."                      "It's a long journey to the physiotherapist."                      "The transport by taxi back and forth to the physiotherapist takes a long time."</p>
Information	<ul style="list-style-type: none"> <li>• Patients had a negative experience in receiving lots of information prior to discharge.</li> </ul>	<p>"It is difficult to keep track of all information before surgery."                      "There were too many redundant information meetings."                      "I've received different kinds of information, so now I'm in doubt."                      "I did not receive the information sheet about the operation."</p>
Training	<ul style="list-style-type: none"> <li>• Patients would like to have the active involvement of a physiotherapist during the rehabilitation.</li> <li>• More visual instructions were preferred.</li> </ul>	<p>"I'm afraid of ruining my knee."                      "I want the physiotherapist to be part of my workout."                      "The exercises are different from those I do at home."</p>
Motivation	<ul style="list-style-type: none"> <li>• Patients lost their motivation to perform the training program over time.</li> </ul>	<p>"I've had a more reduced level of functioning."                      "The rehabilitation has gone wrong, and it has gone beyond my motivation."                      "My motivation for training has fallen as my knee has gotten better."</p>

screens. Two wireless motion sensors were also utilized to track the user's exercises based on the provided method in Naeemabadi et al.<sup>47</sup> Figure 6 shows the paper drawing of the home page of the TRP software and the corresponding developed GUI.

**Iteration 3: second workshop**

Findings from the first working group are categorized into messaging, training, and information for the patient's themes and stated in Table 5.

In the second working group, it was decided that the TRP should be based on the following requirements:

- Healthcare professionals should have access to the patients' data with an individualized two-factor authentication;
- The TRP should present an 8-week rehabilitation program;
- Healthcare professionals should be able to define and update patients' exercise programs;
- The patients are asked to report their pain level and knee circumference every third day;
- The patients are asked to report their knee score using the Oxford Knee Score<sup>48</sup> every 14 days;

**Table 4.** Workshop ideas.

Themes	Steps	Ideas
Communication	BO	Communication via email. Phone in case of panic; otherwise, email or SMS. Possibility to ask questions about pain via the knee portal. Video communication with hospitals for asking questions and training exercises.
	RE	Booking of time for consultation with a physician or physiotherapist. Possibility to email the hospital and in case of acute problems, to contact the nurse.
	AR	“Patient kiosk questions” about how to adjust to specific problems in everyday life?
Information	BO	Information on the knee portal must be visual. Video about how the operation takes place.
	RE	Information videos about pain, footwear, and the importance of exercise. Video about painkillers (doctor or nurse). What and why?
Training	BO	Start training before surgery for knowledge of the exercises. Instruction or training in relevant exercises and walking up and downstairs.
	RE	The system must be compatible with TV and tablet. Feedback about the exercises is performed correctly. “Live training” with the physiotherapist.
	AR	The possibility of participating in post-self-training rehabilitation.
Motivation	BO	Sensors help motivate the patients to exercise. Sensors create a disturbance in exercise and everyday life.
	RE	An exercise log will motivate patients to exercise. The patient must be challenged to the right level via an individual training program. The patient can follow his or her development.
	AR	A physiotherapist should motivate them after 8 weeks of training.

BO: before the operation; RE: during the rehabilitation period; AR: after rehabilitation.

Ideas generated in the first working groups were divided into four themes in three periods (steps). The three steps refer, respectively, to the period before the operation (BO), during the rehabilitation period (RE), and after rehabilitation (AR).



**Figure 6.** Paper drawing of (a) the first page of the application and (b) graphical user interface of the application.

**Table 5.** Generated ideas in the first working groups divided into GUI design, contents, and information themes.

Themes	Findings
Messaging	<ul style="list-style-type: none"> <li>• The system should notify the users once a new message is received.</li> <li>• The message system must be able to show the sender's name.</li> <li>• A graphic explanation on reporting pain levels should be explained.</li> <li>• Video messaging may not be very useful.</li> </ul>
Training	<ul style="list-style-type: none"> <li>• Videos of the exercises with proper instruction should be given in the training program.</li> <li>• The system shall show the number of performed and the exercises remaining to be done for each day.</li> <li>• Information should be provided about why the users shall perform each exercise.</li> </ul>
Information	<ul style="list-style-type: none"> <li>• Contact information with the healthcare sector.</li> <li>• Provide an emergency phone number that can be used in connection with pain.</li> <li>• Description of medicine and its effect.</li> <li>• Videos of the information material.</li> <li>• Everyday challenges explained with text and images.</li> </ul>

GUI: graphical user interface.

**Table 6.** The verbal and non-verbal findings collected in the third working group, while the users were performing the given tasks.

Themes	Findings
User-friendliness of GUI	<ul style="list-style-type: none"> <li>• Users were uncertain whether should they click or tap on the icons once or twice.</li> <li>• Four out of eight test users had doubts about how to report pain.</li> <li>• Half of the users were in doubt about where to find "own messages".</li> </ul>
User-friendliness of sensors or training	<ul style="list-style-type: none"> <li>• The thumbnail animation of the exercise confused the patients.</li> <li>• It was not clear how to select each exercise, and when the sensors started to operate.</li> </ul>
Time elapsed	The most significant difference in the elapsed time was seen when the users had to report the pain.
Non-verbal expression	Users were confused due to the crowded GUI.

GUI: graphical user interface.

- The healthcare professional should be able to track patients' reports and adherence to the exercise program visually;
- Two-way communication should be established between users.

Finally, in the last working group, both participatory observations and time spent on each task were collected. Table 6 shows the findings of participant-observation conducted while participants were performing the tasks.

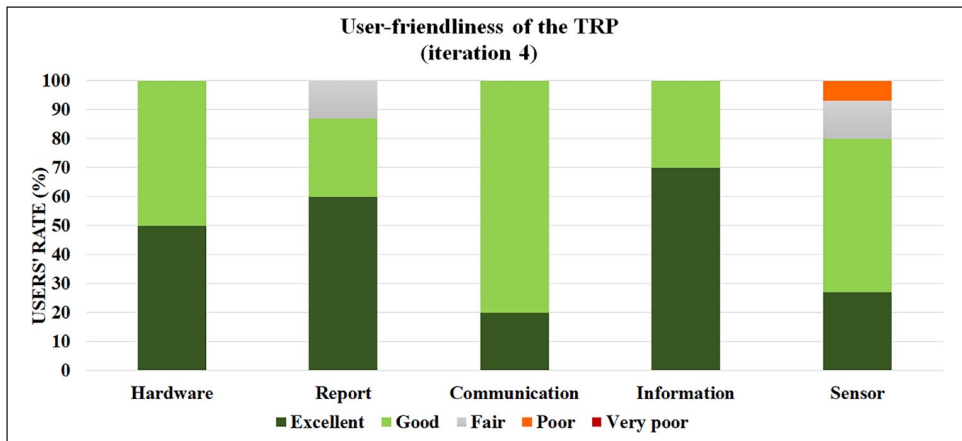
#### *Iteration 4: home test*

The qualitative findings of the interview were grouped into four themes. These are shown in Table 7.

**Table 7.** Themes and findings in the first home test.

Themes	Findings
User-friendliness of GUI	<ul style="list-style-type: none"> <li>• The history of reports should be more precise and natural.</li> <li>• Swelling in the knee should be trackable using the history of the report.</li> <li>• Providing precise details on how to measure and report PRO data.</li> <li>• Providing adjustable text and buttons sizes on the information portal.</li> </ul>
User-friendliness of the hardware	<ul style="list-style-type: none"> <li>• The system login (authentication) should be much more user-friendly.</li> <li>• There should be a possibility to use a tablet with or without a keyboard.</li> <li>• The audio in the videos should have higher quality.</li> </ul>
Ease of use of sensors	<ul style="list-style-type: none"> <li>• There should be more information in the video about the application of sensors.</li> <li>• Four out of the five patients had a problem with connecting to the sensors.</li> <li>• The sensor registration process was not user-friendly.</li> </ul>
User experience with the TRP concept	<ul style="list-style-type: none"> <li>• The history of exercises provides insight into your training.</li> <li>• The contact person should answer messages every time.</li> <li>• It was motivating that the sensors provided feedback on whether the exercises were being performed successfully.</li> <li>• Test subjects did not mind having the system installed in their homes.</li> </ul>

GUI: graphical user interface; PRO: patient-reported outcomes; TRP: telerehabilitation program.



**Figure 7.** Reported user-friendliness of the developed TRP tested in the fourth iteration using a 5-point Likert-type questionnaire.

The finding on the user-friendliness of the TRP was divided into five categories: hardware, reporting system (PRO data), communication, information, and training using the wearable sensors. Figure 7 shows the reported users’ experiences with TRP. Figure 7 indicates that the overall user-friendliness of the TRP was high to very high. It should be mentioned that the patients reported a lower level of satisfaction in the area of communication and training with the wearable sensors.

*Iteration 5: telerehabilitation application test for 2 weeks*

The themes and finding on the 2-week TRP test are presented in Table 8.

**Table 8.** Themes and findings on the 2-week system test (iteration 5).

Themes	Findings
Communication	<ul style="list-style-type: none"> <li>• The established communication reduced the demand for transportation.</li> <li>• The level of motivation among patients increased.</li> <li>• The demand for regular communication was satisfied.</li> </ul>
Training	<ul style="list-style-type: none"> <li>• Adherence to the personalized training program was improved.</li> <li>• Higher motivation was achieved.</li> <li>• A higher level of self-confidence was reported.</li> </ul>
Information	<ul style="list-style-type: none"> <li>• Users could easily find relevant information using the information portal.</li> </ul>
Confidence and privacy	<ul style="list-style-type: none"> <li>• Patients felt more confident by having regular electronic communication with and feedback from a physiotherapist.</li> <li>• The patient did not feel the TRP disturbed their privacy.</li> </ul>
User-friendliness	<ul style="list-style-type: none"> <li>• The TRP introduced a higher level of time flexibility, as there was less need to schedule in-person visits to the clinic.</li> <li>• The system was portable and user-friendly.</li> </ul>

TRP: telerehabilitation program.

The achieved results from the semi-structured interview revealed five distinct groups, reflecting the participants' experiences while using the TRP and the encountered facilitators and barriers during 2 weeks.

*Virtual training.* The users stated that the program facilitated training at home and helped them to have higher adherence to the rehabilitation program. Two of the patients remarked that the virtual training assisted and motivated them in carrying out their training exercises:

It has advantages that the program is highly structured, and I do the exercises in a structured order. (ID 206)

The patients also remarked that the TRP motivated them to perform the exercises without any ambiguity:

Because I have said "Yes" to participate in the project, I don't want to fail to exercise. (ID 205)

One of the patients remarked that group training might motivate her more than exercising at home. She stated,

It is a lonelier form of training than team training, where one can encourage each other, and the individual training requires a lot of discipline. (ID 206)

*Communication.* All the participants agreed the asynchronous communication platform that was provided was a significant help in facilitating communication with the healthcare professional, and they received the proper support. The patient mentioned that they could resolve many of the challenges and problems using the system. For example,

and if I had problems, you [referring to healthcare professional] were there right away. (ID 205)

Moreover, one of the participants thought that consulting with a healthcare professional motivated him to remain involved in the program. He stated,

I have used the sending messages [using TRP], and it is user-friendly for someone who is not used to computers. (ID 209)

One of the participants also shared his thoughts and experiences using phone calls as the potential alternative to digital communication:

I don't think there is much support you get from the hospital from that angle. (ID 209)

The majority of the users claim that the system can considerably reduce the need for travel. One of the patients stated that the multimedia services and instructions for the exercises satisfied the requirement for attending the physiotherapy center. One participant mentioned,

It's great that you can do it at home and be guided in it, so you don't have to travel back and forth to the physiotherapist. (ID 209)

**Information.** Almost half of the patients remarked that they were interested in reading the information provided. However, they remarked that the information was provided in the user-friendly platform, and they were able to navigate through various types of information. One of the participants stated,

It's easy to navigate in, and I've read it all several times. (ID 207)

**The sense of feeling secure and privacy.** The participants believed that physiotherapist's feedback on the patients' performance and questions induced a sense of security. A typical remark was

At one point, you [the physiotherapist] wrote to me and gave me feedback on the exercises, and that means something to me that there is some response that it's being done the right way. (ID 206)

The majority of the participants remarked that the system did not invade their privacy, and they felt comfortable using the program:

I do not feel unpleasant that someone is keeping an eye on me. (ID 206)

I did not feel monitored. It's when the exercises are not made to feel monitored. (ID 209)]

When one of the patients realized that the TRP uses the tablet webcam—the TRP has a tablet webcam, even though it was not used. She added that

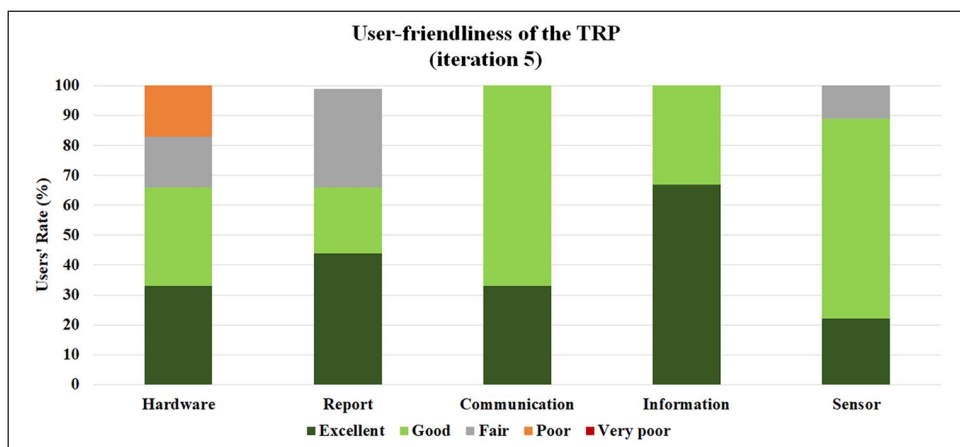
I have thought about whether someone could see me if I did not have clothes on while in front of the tablet. (ID 205)

**Mobility, flexibility, and user-friendliness of the system.** Most of the patients remarked that the TRP introduced a high level of portability and that they could, therefore, use the system outside their home. One of the interviews was conducted at the patient's summer cottage while the patient was using the program there. Moreover, one of the patients stated that

I have had the system in the summer cottage seven days after surgery. (ID 209)

One of the other patients also remarked that they might have a higher level of flexibility compared to face-to-face rehabilitation:





**Figure 8.** Reported user-friendliness of the final TRP in the last iteration using a 5-point Likert-type scale questionnaire.

The advantage is that you can train at home and whenever you want. (ID 207)

Figure 8 shows the experiences of the recruited patients in the second phase of the study after patients had used the final TRP for 2 weeks.

## Discussion

The aim of this study was to develop an individualized TRP. The program consisted of a fieldwork data collection, two PD workshops, and two system tests and users' feedback. This achievement of study can be used as a guide for developing a sensor-based TRP that satisfies the patients' requirements. Therefore, future studies might use these program design specifications to improve the current TRPs for the target.

Therefore, the main stakeholders (patients and healthcare professionals) were invited to participate in the system design and test. Eight participants who previously had regular rehabilitation program and four healthcare professionals were recruited in the development and design process. Three of the former patients were lost in the follow-up, and only five of them attended all the development iterations. Nielsen and Landauer<sup>49</sup> suggested that a sample of five users can uncover 75–80 percent of the usability issues in the design of user-centered systems. Hence, five patients are considered to be adequate to uncover issues for further investigation.

It was found that those patients who received the self-training program after a TKR still faced several challenges in carrying out their training program. Lack of regular healthcare supervision, communication, as well as lack of explicit knowledge of the patient's adherence to the rehabilitation program were reported as main barriers of the program. Allin et al.<sup>50</sup> also reported that users might need different kinds of information, while some of them may use the Internet to find particular information. Wiklund Axelsson et al.<sup>51</sup> also indicated that the study group reported a feeling of being abandoned due to the lack of continuous communication.

The workshops (iterations 2 and 3) revealed that providing electronic communication between patients and healthcare professionals (i.e. physiotherapists and nurses) can resolve some of the current challenges. Furthermore, the patients expected to have access to relevant information via

multimedia content. Healthcare professionals also requested regular patients' reports on adherence to the exercise and relevant outcomes. As a result, they can provide appropriate feedback or intervention for each patient individually, thus enabling the professionals to prescribe a personalized rehabilitation program for each patient. Also, the users may track their progress in the program. The users emphasized that they are more motivated by establishing two-way communication and interactive report-feedback platform with healthcare professionals. This finding is in line with Petrusdottir et al.,<sup>52</sup> who reported that motivation might facilitate adherence to the exercise program among individuals with osteoarthritis. Jakobsen et al.<sup>53</sup> also indicated that increased communication among users led to higher user involvement. Danbjørg et al.<sup>54,55</sup> emphasized the importance of asynchronous communication between users and healthcare personnel in order to avoid feeling being unsupervised.

The qualitative results from the preliminary system test (iterations 4 and 5) indicated that the patients' requirements were fulfilled: patients reported that the system had a very high level of user-friendliness. However, the users in the fifth iteration did not participate in the development of the TRP. This might be considered as an advantage of the testing process compared to previous studies that involved the same participants in their study.<sup>54,56</sup> The data collected in the last iteration (iteration 5) showed that the patients felt more confident, more secure, more supported, and had a higher level of motivation to follow the personalized rehabilitation program. Danbjørg et al.<sup>55</sup> also obtained a similar finding and indicated that it caused an increase in users' sense of security. Luna et al.<sup>57</sup> stated that user satisfaction was higher in comparison with conventional methods, which also showed similar results in this study.

PD as a method is an iterative process with several benefits and challenges. The main benefit of this approach is identifying the real user needs as well as establishing a constructive dialogue among the stakeholders, which leads to finding a better match between the requirements and available technologies. In this study, a higher level of satisfaction was reported by the user in the real-world settings (fifth iteration); however, they did not participate in the design process.

Two challenges were observed in this study. First, PD is highly resource-demanding, and the data collection and processing were time-consuming and required the participation of stakeholders, which is in agreement with the findings of Clemensen et al.<sup>33</sup> Furthermore, actively engaging stakeholders in the iterative design process were challenging to achieve and require experienced facilitators. One of the participants left the project due to a lack of interest. That might occur as a result of the heterogeneity of participants' backgrounds. Danbjørg et al.<sup>55,58</sup> also reported difficulties with engaging participants.

This study had four limitations. First, there was a limited number of stakeholders participating in the study (eight patients and four healthcare professionals) and test (four patients) processes. Second, the TRP was tested for only a short period (2 weeks), and patients might have different experiences if followed over an extended period. In addition, the age group of the participants who involved in the development and testing (last iteration) were not in the same range, which might have an impact on the obtained results. Therefore, further studies should investigate the usability and feasibility of TRP with a higher number of patients, for a longer time in the patients' homes. Finally, the patients with no conflicting health condition participated in the development process; therefore, the recommendations for the system cannot be generalized to the rest of the communities. Further studies are required to conduct with patients with conflicting conditions.

## Conclusion

A TRP for patients undergoing TKR was developed using PD. This study developed a sensor-based TRP, and preliminary patient testing showed a high level of patient-reported user-friendliness and

acceptability. Future developments, testing, and evaluation with patients and healthcare professionals are required so as to ensure the effectiveness and user-friendliness of the system.

### Acknowledgements

The authors thank the Department of Occupational Therapy and Physiotherapy, Aalborg University Hospital and Orthopedic Surgery Research Unit, Research, and Innovation Center, Aalborg University Hospital, for participating in this study.

### Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.



### Ethical approval

This study was conducted according to the Declaration of Helsinki, and all participants signed an informed consent form. This study was submitted to the local Ethics Committee for review, and as no intervention will be performed, it is not necessary to report this study to the Ethics Committee, according to national legislation in Denmark (S-20180012). Ethical approval for the second phase of this study was obtained from the local Ethics Committee (ID: N-20110171).

### Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by the Aage and Johanne Louis-Hansen Foundation and Aalborg University.

### ORCID iDs

MReza Naeemabadi  <https://orcid.org/0000-0002-9448-0871>  
Katherine K Kim  <https://orcid.org/0000-0001-5766-3938>

### References

1. Artz N, Elvers KT, Lowe CM, et al. Effectiveness of physiotherapy exercise following total knee replacement: systematic review and meta-analysis. *BMC Musculoskelet Disord* 2015; 16: 15.
2. Szöts K, Pedersen PU, Hørdam B, et al. Physical health problems experienced in the early postoperative recovery period following total knee replacement. *Int J Orthop Trauma Nurs* 2015; 19(1): 36–44.
3. Lee FKL, Lee TFD and So WKW. Effects of a tailor-made exercise program on exercise adherence and health outcomes in patients with knee osteoarthritis: a mixed-methods pilot study. *Clin Interv Aging* 2016; 11: 1391–1402.
4. Hall AM, Ferreira PH, Maher CG, et al. The influence of the therapist-patient relationship on treatment outcome in physical rehabilitation: a systematic review. *Phys Ther* 2010; 90(8): 1099–1110.
5. Baker KR, Nelson ME, Felson DT, et al. The efficacy of home based progressive strength training in older adults with knee osteoarthritis: a randomized controlled trial. *J Rheumatol* 2001; 28(7): 1655–1665.
6. Saywell N and Taylor D. Focus group insights assist trial design for stroke telerehabilitation: a qualitative study. *Physiother Theory Pract* 2015; 31(3): 160–165.
7. Lemaire ED, Boudrias Y and Greene G. Low-bandwidth, Internet-based videoconferencing for physical rehabilitation consultations. *J Telemed Telecare* 2001; 7(2): 82–89.
8. Kingston GA, Judd J and Gray MA. The experience of medical and rehabilitation intervention for traumatic hand injuries in rural and remote North Queensland: a qualitative study. *Disabil Rehabil* 2015; 37(5): 423–429.
9. Finkelstein SM, Speedie SM, Demiris G, et al. Telehomecare: quality, perception, satisfaction. *Telemed J E Health* 2004; 10(2): 122–128.

10. Demiris G, Speedie SM and Finkelstein S. Change of patients' perceptions of telehomecare. *Telemed J E Health* 2001; 7(3): 241–248.
11. Russell TG, Buttrum P, Wootton R, et al. Internet-based outpatient telerehabilitation for patients following total knee arthroplasty: a randomized controlled trial. *J Bone Joint Surg Am* 2011; 93(2): 113–120.
12. Moffet H, Tousignant M, Nadeau S, et al. In-home telerehabilitation compared with face-to-face rehabilitation after total knee arthroplasty: a noninferiority randomized controlled trial. *J Bone Jt Surg* 2015; 97: 1129–1141.
13. Tousignant M, Moffet H, Boissy P, et al. A randomized controlled trial of home telerehabilitation for post-knee arthroplasty. *J Telemed Telecare* 2011; 17(4): 195–198.
14. Moffet H, Tousignant M, Nadeau S, et al. Patient satisfaction with in-home telerehabilitation after total knee arthroplasty: results from a randomized controlled trial. *Telemed J E Health* 2017; 23(2): 80–87.
15. Tousignant M, Boissy P, Moffet H, et al. Patients' satisfaction of healthcare services and perception with in-home telerehabilitation and physiotherapists' satisfaction toward technology for post-knee arthroplasty: an embedded study in a randomized trial. *Telemed J E Health* 2011; 17(5): 376–382.
16. Boissy P, Tousignant M, Moffet H, et al. Conditions of use, reliability, and quality of audio/video-mediated communications during in-home rehabilitation teletreatment for postknee arthroplasty. *Telemed J E Health* 2016; 22(8): 637–649.
17. Tousignant M, Boissy P, Corriveau H, et al. In home telerehabilitation for older adults after discharge from an acute hospital or rehabilitation unit: a proof-of-concept study and costs estimation. *Disabil Rehabil Assist Technol* 2006; 1(4): 209–216.
18. Tousignant M, Moffet H, Nadeau S, et al. Cost analysis of in-home telerehabilitation for post-knee arthroplasty. *J Med Internet Res* 2015; 17(3): e83.
19. Rogante M, Grigioni M, Cordella D, et al. Ten years of telerehabilitation: a literature overview of technologies and clinical applications. *Neurorehabilitation* 2010; 27(4): 287–304.
20. Vollenbroek-Hutten M, Jansen-Kosterink S, Tabak M, et al. Possibilities of ICT-supported services in the clinical management of older adults. *Aging Clin Exp Res* 2017; 29(1): 49–57.
21. Kushniruk AW and Patel VL. Cognitive and usability engineering methods for the evaluation of clinical information systems. *J Biomed Inform* 2004; 37(1): 56–76.
22. Zanaboni P and Wootton R. Adoption of telemedicine: from pilot stage to routine delivery. *BMC Med Inform Decis Mak* 2012; 12: 1–9.
23. Armfield NR, Edirippulige SK, Bradford N, et al. Telemedicine is the cart being put before the horse. *Med J Aust* 2014; 200(9): 530–533.
24. Kushniruk A and Nøhr C. Participatory design, user involvement and health IT evaluation. *Stud Health Technol Inform* 2016; 222: 139–151.
25. Pilemalm S and Timpka T. Third generation participatory design in health informatics—making user participation applicable to large-scale information system projects. *J Biomed Inform* 2008; 41: 327–339.
26. Lyng KM and Pedersen BS. Participatory design for computerization of clinical practice guidelines. *J Biomed Inform* 2011; 44(5): 909–918.
27. Orji R, Oyibo K, Lomotey RK, et al. Socially-driven persuasive health intervention design: competition, social comparison, and cooperation. *Health Informatics J* 2019; 25: 1451–1484.
28. Orji R and Moffatt K. Persuasive technology for health and wellness: state-of-the-art and emerging trends. *Health Informatics J* 2018; 24(1): 66–91.
29. Nielsen JA and Mengiste SA. Analysing the diffusion and adoption of mobile IT across social worlds. *Health Informatics J* 2014; 20(2): 87–103.
30. Ruxwana NL, Herselman ME, Pottas D, et al. Advocating a quality assurance model for the implementation of e-health solutions in rural South Africa. *Heal Inf Manag J* 2016; 39: 36–40.
31. Donnelly N, Butler-Henderson K, Chapman M, et al. The development of a classification system for maternity models of care. *Health Inf Manag* 2016; 45(2): 64–70.
32. Wolters MK, Kelly F and Kilgour J. Designing a spoken dialogue interface to an intelligent cognitive assistant for people with dementia. *Health Informatics J* 2016; 22(4): 854–866.
33. Clemensen J, Rothmann MJ, Smith AC, et al. Participatory design methods in telemedicine research. *J Telemed Telecare* 2017; 23(9): 780–785.

34. Ryan RM, Patrick H, Deci E, et al. Facilitating health behaviour change and its maintenance: interventions based on self-determination theory. *Eur Heal Psychol* 2008; 10: 2–5.
35. Spinuzzi C. The methodology of participatory design. *Tech Commun* 2005; 52: 163–174.
36. Larsen SB, Sorensen NS, Petersen MG, et al. Towards a shared service centre for telemedicine: telemedicine in Denmark, and a possible way forward. *Health Informatics J* 2016; 22(4): 815–827.
37. Vinet L and Zhedanov A. A “missing” family of classical orthogonal polynomials. *J Phys A-Math Gen* 2011; 44: 085201.
38. Spradley JP. *Participant observation*. Long Grove, IL: Waveland Press, 2016.
39. Thoring K, Desmet P and Badke-Schaub P. Creative environments for design education and practice: a typology of creative spaces. *Des Stud* 2018; 56: 54–83.
40. Gaver B, Dunne T and Pacenti E. Design: cultural probes. *Interactions* 1999; 6: 21–29.
41. Kanstrup AM, Bertelsen P and Nohr C. Patient innovation: an analysis of patients’ designs of digital technology support for everyday living with diabetes. *Health Inf Manag* 2015; 44(1): 12–20.
42. Hamm J, Money AG, Atwal A, et al. Mobile three-dimensional visualisation technologies for clinician-led fall prevention assessments. *Health Informatics J* 2019; 25(3): 788–810.
43. Basch CE. Focus group interview: an underutilized research technique for improving theory and practice in health education. *Health Educ Q* 1987; 14(4): 411–448.
44. Naemabadi M, Dinesen B, Andersen OK, et al. Developing a telerehabilitation programme for post-operative recovery from knee surgery: specifications and requirements. *BMJ Health Care Inform* 2019; 26(1): e000022.
45. Kvale S and Brinkmann S. *Interviews: learning the craft of qualitative research interviewing*. Los Angeles, CA: SAGE, 2009.
46. Ruland CM, Starren J and Vatne TM. Participatory design with children in the development of a support system for patient-centered care in pediatric oncology. *J Biomed Inform* 2008; 41(4): 624–635.
47. Naemabadi M, Dinesen B, Andersen OK, et al. Evaluating accuracy and usability of Microsoft Kinect sensors and wearable sensor for tele knee rehabilitation after knee operation. In: *Proceedings of the 11th international joint conference on biomedical engineering systems and technologies*, Funchal, 19–21 January 2018, pp. 128–135. Setúbal: SciTePress—Science and Technology Publications.
48. Jenny JY and Diesinger Y. The Oxford knee score: compared performance before and after knee replacement. *Orthop Traumatol Surg Res* 2012; 98(4): 409–412.
49. Nielsen J and Landauer TK. Mathematical model of the finding of usability problems. In: *Proceedings of the conference on human factors in computing systems*, Amsterdam, 24–29 April 1993.
50. Allin S, Shepherd J, Tomasone J, et al. Participatory design of an online self-management tool for users with spinal cord injury: qualitative study. *JMIR Rehabil Assist Technol* 2018; 5(1): e6.
51. Wiklund Axelsson S, Wikberg-Nilsson A and Melander Wikman A. Sustainable lifestyle change—participatory design of support together with persons with obesity in the third age. *Int J Environ Res Public Health* 2016; 13(12): 1248.
52. Petursdottir U, Arnadottir SA and Halldorsdottir S. Facilitators and barriers to exercising among people with osteoarthritis: a phenomenological study. *Phys Ther* 2010; 90(7): 1014–1025.
53. Jakobsen PR, Hermann AP, Sondergaard J, et al. Development of an mHealth application for women newly diagnosed with osteoporosis without preceding fractures: a participatory design approach. *Int J Environ Res Public Health* 2018; 15(2): 330.
54. Danbjørg DB, Villadsen A, Gill E, et al. Usage of an exercise app in the care for people with osteoarthritis: user-driven exploratory study. *JMIR mHealth uHealth* 2018; 6(1): e11.
55. Danbjørg DB, Wagner L, Kristensen BR, et al. Intervention among new parents followed up by an interview study exploring their experiences of telemedicine after early postnatal discharge. *Midwifery* 2015; 31(6): 574–581.
56. Danbjørg DB, Wagner L and Clemensen J. Designing, developing, and testing an app for parents being discharged early postnatally. *J Nurse Pract* 2014; 10: 794–802.
57. Luna DR, Rizzato Lede DA, Otero CM, et al. User-centered design improves the usability of drug-drug interaction alerts: experimental comparison of interfaces. *J Biomed Inform* 2017; 66: 204–213.
58. Danbjørg DB. *A lifeline connecting new parents with the hospital: using participatory design to develop and test an app for parents being discharged early postnatal*. PhD Thesis, Syddansk Universitet, Odense, 2015.