Exploring the Communication of Progress in Home-based Falls Rehabilitation using Exergame Technologies

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Little is known on how to effectively represent rehabilitation progress, over a period of time, using exercise game (exergame) technologies. Progress in falls rehabilitation, which consists of improved performance in balance and muscle strength, is essential to assuring seniors of a reduced risk of falling. In this paper, we build on our previous research into exergames for falls, and we investigate how an exergame system can be used to communicate long-term progress to seniors. Using a multiphase user-centered requirements gathering process, we first investigated stakeholder perspectives regarding progress in self-managed rehabilitation. Following this we describe the home-based evaluation of our prototype exergame system, which highlights rehabilitation progress, with seniors, over a period of 2 months. Progress, in our system is communicated using charts of exercise performance and frequency, as well as medals awarded for achieving longer-term rehabilitation milestones. We report on seniors’ opinions and preferences regarding the potential of our exergame system to communicate this rehabilitation progress in a meaningful way. Finally we discuss implications for design, based on our studies, to inform the development of more effective exergame systems for long-term unassisted rehabilitation in the home.

CCS Concepts: • Human-centered computing—User studies • Human-centered computing—Field studies

KEYWORDS
Falls, Rehabilitation, HCI, User centred design, UCD, Design, Progress, Quality of movement, Exergames, Medals, Exercise progression

1 INTRODUCTION
Falls are one of the leading causes of death and disability in seniors [35]. About 1 in 3 community dwelling seniors, over the age of 65 years, fall at least once a year [33,35]. Most injurious falls are complicated by fractures, which can lead to death or severe disability in the elderly, and they can be costly (UK £2bn, USA $34bn per annum) to both healthcare services and the individual [19]. The literature suggests that reduced muscle strength and poor balance, normally associated with ageing, are the most prevalent and readily modifiable risk factors for falls [31]. According to recent work, the most successful way to reduce the rate, and risk, of falls is through a multifactorial intervention, involving tailored exercises (or rehabilitation), to improve balance in the elderly [8,10,31]. In many countries, such as the USA and UK, the Otago Exercise Programme (OEP) and the Falls Management Exercise (FaME) programme are the most commonly used interventions, in falls rehabilitation, to ensure effective physical recovery [6,28,33] after a fall. In the UK standard care in falls rehabilitation, which consists of a prescription of exercises from the OEP and FaME, often relies on booklets and videos to communicate information to people undertaking falls rehabilitation (Fig. 1). The main problem with these media is they do not provide any feedback, to the user, on performance and progress [39]; therefore,
seniors do not know whether they are getting better over time. This feedback is important to improving confidence in users and motivating them to exercise more due to the assurance of progress [3,37].

Improved physical function, in most areas of physical rehabilitation, is often recognized as increased range of movement (ROM) in affected limbs/joints, such as the knee [3], shoulder [34], arm [2], and ankle [32]. Most researchers have attempted to communicate progress, by showing improved change in this data [3,32,34]. Showing this change is perhaps easier in research areas such as stroke, knee and shoulder rehabilitation, where the metrics are definite (e.g. range of movement in the knee and shoulder, and reach, or distance, in an affected arm after a stroke). However in falls, the metrics that define rehabilitation are more complex, since there are numerous risk factors involved, with researchers and therapists often focusing on one metric, or risk factor, e.g. improved mobility and balance. Out of these metrics, adherence to exercise (directly influenced by motivation [23,38,39]) has been the main focus of interest in previous research on falls. This is evident in the increased use of visual feedback and computer games to improve therapy and encourage a more enjoyable experience for seniors engaged in physical activity [5,15,26,27,37]. Nevertheless, adherence to exercise does not offer much benefit to rehabilitation if users are not doing the exercises with the correct quality of movement; in fact, this could be detrimental to the user [3], potentially leading to more problems in limb joints [34].

Commercial games (e.g. Nintendo Wii [21,22,41]), while useful to making exercise fun, do not promote the quality of movement necessary for effective recovery in physical rehabilitation [2,37]. Recent work has identified these shortcomings of current off-the-shelf technologies and suggested how specially tailored (modeled on exact exercise movements) exercise games (or exergames) are necessary to ensure effective rehabilitation [27,36]. To date none of these studies have explored the following: a) progress in falls therapy from a home rehabilitation standpoint, b) stakeholder opinions on rehabilitation progress and how it can be effectively communicated over time through exergame systems and c) using a user-centred design (UCD) framework, to identify opportunities for design with regard to communicating progress through exergame technologies. We attempt to fill these gaps by investigating how meaningful rehabilitation progress can be shown, over an extended period of time, and communicated effectively to users through exergame technologies. With this goal in mind, we identified the following research questions:

- Q1: What are the opinions of the main stakeholders (physiotherapists and seniors) on progress in falls rehabilitation?

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• Q2: How can rehabilitation progress be effectively communicated to seniors, undertaking unassisted falls rehabilitation in the home, using an exergame system?

In this paper, we first describe an exergame system developed during our previous work [36,37,38], which utilized a Participatory Design (PD) methodology. Then we discuss our current work, which included an iterative user-centered process to design and integrate progress mechanics, in our exergame system; this was achieved using a requirements gathering study, which included interviews and design workshops with stakeholders (in this paper we define our stakeholders as physiotherapists and seniors at risk of falling). We then describe the evaluation of progress mechanics with seniors in a 2-month user study in the home. We present the findings from both studies and answer our research questions Q1 and Q2. Finally, we conclude by providing insights into stakeholder perspectives regarding falls rehabilitation progress, and we discuss recommendations on how to ensure effective progress communication through exergame systems, in unassisted rehabilitation.

2 RELATED WORK

2.1 Tracking Progress Using Rehabilitation Technologies

Methods of tracking progress, in physical rehabilitation, have been of special interest to researchers in the rehabilitation space [2,11,17]. For instance, Matarić et al. [17] developed a robot that interacted with stroke survivors, through tasks of physical function, in a laboratory study. Their participants responded positively to the assistance provided by the robot, including its ability to communicate progress, in short tasks, using multimodal means. Huang et al. [11] explored animated feedback, for upper limbs, using a bespoke ‘smart glove’ and Microsoft Kinect skeletal tracking. They argue, through their experimental findings, that by observing differences in the animations at different times one could monitor progress in physical rehabilitation. In all of the above studies [11,17], which are indicative of the general research in this area, the communication of performance and progress is investigated in one-off evaluation studies. To some extent, a few researchers have explored how progress can be effectively communicated over a period of time, through rehabilitation technologies, as well as stakeholder opinions on such features. For instance, a study by Ayoade and Baillie [3] describes a rehabilitation system for total knee replacement patients, which was evaluated in a 6-week home study. Bar charts were used to communicate how many repetitions were achieved during exercise sessions. A traffic light gradient of colors (red, yellow, green) was used to indicate performance (quality of movement or QOM) of the repetitions. They found that their stakeholders: a) preferred to view the charts on a weekly basis, as this would be sufficient to show improvement in physical function, and b) could observe which exercises the users needed to improve on, based on the observed progress.

Ayoade & Baillie [3] followed an iterative user-centered process in the design of their rehabilitation system; however, in their work, there is little information on how the progress charts were designed following input from users. Therefore it is difficult to determine the important factors that contribute to the effective design of such functionality in rehabilitation systems. Furthermore, when the users in [3] were able to achieve effective ROM in the knee (green color area of their performance gradient), with relative ease, they wished that they could progress to a more difficult level of exercise. This was not available in the knee rehabilitation system. In our work, discussed in this paper, we enabled progression through varying levels of difficulty, depending on the users’ needs. Also in musculoskeletal rehabilitation, Lam et al. [12] developed a system, called the Automated Rehabilitation System (ARS), a system for physiotherapists to monitor knee and hip replacement patient progress in the clinic. They tracked progress by comparing visualizations of movement at different time periods. In the iStopFalls project [9,24,25,30] researchers undertook the design of a falls risk assessment system, using the Kinect camera, which could be used by seniors in their own homes to assess their risk of falling. However, these works did not go as far as to enable users who had already had a fall undertake rehabilitation (based on balance and strength exercise) exergames in the home.
2.2 Progress in Exergame-Based Systems

Previous research has attempted to explore how exergames can be successfully deployed in various rehabilitation settings [7,13,27,36]. Of those studies that used commercial games, such as the Nintendo Wii [14,21,41] and Microsoft Kinect [14,15,18,29,41], they are restricted to progress in terms of performance in the associated games (e.g. game scores in the *Wii Sports Bowling* game shows how well a game of bowling is played) rather than functional rehabilitation as such. Consequently these generic game scores do little to assure seniors of change in their own actual physical ability [14]. Tailored exergames (games specifically designed for exercise) have been used to alleviate this issue by focusing on functional recovery, e.g. in balance, strength and range of movement [2,41]. By observing improved scores over time, in such tailored exergames, one would be assured of potentially improved physical outcomes.

In recent times, researchers have made advances in communicating measures of progress relevant to rehabilitation using tailored exergame systems. For instance, Schoene et al. [30] developed a system that required a pressure mat for step training in balance recovery; the system also recorded step reaction time in seniors. Progress, in Schoene et al.’s work consisted of showing improved step reaction, which highlights a reduced fall risk [16,25,30]. While this work is important to assuring progress from a step reaction perspective, it does not represent falls rehabilitation from a practice point of view. Indeed, previous work on tailored exergames has often focused on single fall prevention interventions mostly used in research [25,30], rather than real-world current care, i.e. existing home exercise. Our work is unique in that we investigate progress in physical rehabilitation currently adopted in practice in many western countries, i.e. based on the OEP and FaME rehabilitation programmes (Fig. 1).

The current work, described in this paper, follows on from previous work where we designed and developed our exergame system to encourage effective physical rehabilitation [36,37,38] after a fall. Therefore, we adopted this approach, seeking to define falls rehabilitation progress and how to effectively communicate progress over time through an exergame system. In section 3, we provide a summary description on our exergame system and explain how the individual games satisfy therapy in falls; this will provide context for the inclusion of progress mechanics (which is the focus of this paper) in the next phase of design and development.

2.3 User-Centred Design in Rehabilitation Systems

Recent work advocates for the employment of an iterative user-centred design (UCD) approach in order to accomplish the successful design of such technologies [9,45]. Such UCD methods have often included one-off user testing and design sessions, where stakeholders make recommendations for redesign, after using the system [2,13,42,43,44]. By involving the main stakeholders in the design process, in these cases, recommendations have been made regarding the design of more effective technologies for rehabilitation. To ensure that seniors’ concerns on the use of technologies for rehabilitation are addressed, it is important to involve them in the design of these technologies [2,3,42]. In one example, Alankus et al. [2] found that involving seniors can inform the design of more enjoyable exergames for upper limb rehabilitation in stroke. The findings were similar in the study by Lange et al. [13], where study participants suggested redesigning an exergame for balance training. The advantages of employing UCD methods are not limited to the design of exergames, however. For example, in a knee rehabilitation study by Ayoade and Baillie [3], senior participants also responded positively to visual feedback on their performance, not least because their progress charts (co-designed by seniors) were found to be simple, effective and useful for communicating exercise performance over time [3]. In another study, Doyle et al. [42] evaluated various functions of their movement visualization rehabilitation system with their users; the user feedback in this study was also found to be essential to making the system more effective for rehabilitation.

Indeed in our previous work on the design of exergames for falls rehabilitation [36,38], we have demonstrated the effectiveness of stakeholder feedback in informing the design of an effective exergame-based rehabilitation system for the home. Therefore, it is evident that UCD can be an effective way to inform the design of more useful and effective rehabilitation technologies, by understanding the main stakeholder concerns and adapting the design of the technologies to better suit their needs. As with our previous work, we adopt UCD principles in
this work on the design of progress mechanics for our exergame system. The specific need, in this case, is to understand how rehabilitation progress can be represented and communicated to users in a way that is easy to understand and accessible. Given that the users of our system are seniors, we believed that they could best provide us with meaningful insights into whether our designs are useful in a real world rehabilitation scenario.

3 SYSTEM DESCRIPTION

3.1 Summary of Our Previous work

Our initial goal was to design and develop an exergame system that provides a suitable alternative to deliver exercise, used in standard care by seniors undertaking falls rehabilitation in the home. In the UK, this standard care consists of a booklet, or video, containing a set of strength and balance exercises that can be followed (Fig. 1). Using an iterative UCD process, we developed the exergame system, first using a participatory design (PD) methodology in design workshops [38,39], then in multiple user studies [36]. Finally, we evaluated the use of the exergames in the home over a period of 12 weeks [37]. The findings, from our home study, suggest that the exergames encouraged improved physical function and adherence to home rehabilitation, versus standard care.

As expert game designers in the HCI field, our approach to design involves creating concepts and eliciting user responses to those concepts, in certain cases actively involving users in the design, following HCI principles, as evident in our previous work [36,37,38,39]. We adopted this approach in the current investigation with a focus on designing functionality for the system around progress and progression.

3.2 System Description

Six exergames were developed for the system. The basic mechanics of each game were informed by effective quality of movement (QOM) in standard care – taken from the OEP and FaME [6,28,33] exercise programs. The design of the exergames is not the focus of this paper; however, it is necessary to describe the exergames to show how they could assure seniors of maximum therapy in the home. This would provide context for the focus on rehabilitation progress, which is reliant on quality of movement (QOM). We also briefly describe our motion sensing technologies, through which users could interact with the system.

3.2.1 The Fire Rescue Game (Front Knee Strengthening Exercise)

This game is based on the ‘Front Knee Strengthening’ exercise from the OEP/FaME programmes. In the exercise, users are instructed to sit down on a chair, fully extend one leg, at the knee, and hold this position for 3 seconds; they then lower the leg and repeat the movement with the other leg. The whole process is done 10 times (repetitions) to complete the exercise. In the corresponding exergame, the goal is to rescue characters from a burning building, using a platform pivoted to a fire truck (Fig. 2).

Fig. 2. The Fire Rescue Exergame (Inset: leg movement).
The player uses the extension, and flexion, movements of each leg to control the movement of the platform. This exercise emphasizes slow movements, and holding the leg at the top, for maximum strength building in the thigh; to ensure QOM, through the exergame, the player holds their leg at full extension and waits 3 seconds for a character to climb out of the window and onto the platform. Failing this, or lowering the platform too quickly, makes the character fall into the water below, thereby losing a point. The player has to rescue 20 characters in total (10 repetitions on each leg). One point is given for each successful save; therefore, higher scores demonstrate compliance with effective QOM for the Front Knee Strengthening exercise.

3.2.2 The Snow Flags Game (Side Hip Strengthening Exercise)
The goal of this game is to collect as many flags as possible, with an in-game character that ‘snowboards’ down a ski slope (Fig. 3). When the left leg is lifted, the character moves to the right side of the screen, and vice versa. Four flags are placed, alternately, on each side of the screen to encourage the player to hold each leg in place until all 4 flags are collected for each repetition. The game ends after 10 repetitions have been achieved. Each collected flag contributes 1 point to the total score; hence higher scores indicate better adherence to QOM.

Fig. 3. The Snow Flags Exergame.

### Table 1. Additional exergames including a description of the game and its conformance with therapy

<table>
<thead>
<tr>
<th>Game (Exercise)</th>
<th>Procedure</th>
<th>Game details and ensuring quality of movement (QOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigeon Express (Sit-to-stand exercise)</td>
<td>The user sits down and stands up slowly and in a controlled manner</td>
<td>The player controls the flight of a Pigeon. By standing, the pigeon flies upward, and by sitting, it flies downwards. The goal is to catch fruits that fall out of a van and are arranged according to a sine wave. This encourages controlled movement between sitting and standing.</td>
</tr>
<tr>
<td>River Gems (Side steps exercise)</td>
<td>The user stands behind a chair and slowly steps from side to side</td>
<td>The player controls a beaver, which jumps from a floating log to another depending on the step direction. Gems approach the character on either side of the screen. The goal is to get as many gems as possible – these appear on different sides of the screen, requiring the player to step from side to side in a controlled way.</td>
</tr>
<tr>
<td>Panda Peak (Marching exercise)</td>
<td>The user marches at a steady pace</td>
<td>The player controls the movement of a Panda walking across a log covered in snow. The goal of the game is to get to the end of the log. The Panda walks faster according to the player’s pace, and it falls off the log if the player moves too fast.</td>
</tr>
<tr>
<td>Horse Hurdles (Knee bends exercise)</td>
<td>The user bends into a ‘half squat’ position and stands after 3 seconds</td>
<td>The player controls a Horse to successfully jump over a certain number of hurdles. The Horse gallops faster and builds up power when the player bends at the knee. Standing up makes the horse jump high, depending on how long the squat was held for. The horse is only able to jump high enough to clear the 10 hurdles if the player holds each bend.</td>
</tr>
</tbody>
</table>
3.2.3 Inertial (IMU) Sensors
To interact with digital games, it is necessary to have a control mechanism to play. In the literature, on digital games in health, a wide variety of sensor technologies have been exploited, to enable seamless interaction by users. The most commonly used sensors have included camera-based technologies, such as the Microsoft Kinect sensor [9,15,34] and inertial measurement units (IMUs), such as the Nintendo Wii remote controller [2, 21] and other standalone IMUs [1,20,40]. While all of these sensor systems have proved to be effective for their respective various purposes, we found camera-based systems unsuitable for delivering unassisted home-based falls rehabilitation exercises, mainly due to problems with camera tracking [34]. Furthermore, because seniors need to use household furniture as a support aid (e.g. chair as in Fig. 1), there are potential additional tracking problems due to occlusion [11,34]; hence we used IMU sensors in our work.

3.2.4 Interaction Method
The system comprised of a laptop computer, with the exergames installed, as well two IMU sensors. The users were able to interact with the system using the numerical keys on the laptop keyboard. To make the controls more accessible, keyboard stickers were used to highlight the keyboard keys required to interact with the system (numerical keys 1 to 9 and the left and right arrow keys). On each leg, one sensor was strapped to either the thigh or shin, depending on the exergame.

3.3 The Current Work
Our previous work focused on the design of the exergames, shown in Fig. 3, Fig. 4 and Table 1, and the effects of the use of these exergames on adherence (and motivation) to exercise, as well as outcomes of physical function. In our previous work, the exergame system prototype did not have any functionality to track progress; therefore at that time we carried out no investigation into the design of progress or progression mechanics. The current work differs from previous work in the sense that it touches on communicating rehabilitation progress, and it focuses more on a design journey, highlighting the outcomes from the user-centered process that shaped the design of the system components that deal specifically with progress and progression. Furthermore, the current work is a purely qualitative study on design, rather than a quantitative evaluation of the system, as was the case with our previous work [36,37,38]. Therefore this paper does not touch on adherence to exercise or physical function but rather stakeholder views on the importance of progress to home-based falls rehabilitation.

4 STUDY 1: REQUIREMENTS GATHERING

4.1 Procedure
In the current work, the first study employed a multiphase requirements gathering process to determine stakeholder opinions on falls rehabilitation progress and how this is managed in practice; the process included 3 smaller studies (phases): a one-to-one interview with physiotherapists and two design workshops (Table 2).

Table 2. Requirements gathering study procedure highlighting the various phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Methods</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design workshop (1)</td>
<td>Workshop to discuss seniors’ experiences with our exergame system and discuss progress.</td>
</tr>
<tr>
<td>2</td>
<td>Interview</td>
<td>One-to-one interviews with physiotherapists, within the local falls service, to discuss important metrics for performance/ progress.</td>
</tr>
<tr>
<td>3</td>
<td>Design workshop (2)</td>
<td>Workshop, with physiotherapists and seniors, to explore prototypes showing performance/ progress.</td>
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</table>
In the interview (Phase 2), participants (physiotherapists only) were shown various functions of our prototype exergame system, such as the exergames, prototype progress charts and medals (discussed later in the paper). The interview questions focused on a range of topics regarding communicating progress, e.g. game scores, physiotherapists’ and seniors’ rehabilitation goals, rehabilitation milestones and recovery expectations.

Design workshops are useful for promoting active engagement, in design, with a variety of stakeholders. We used 2 design workshops (Phases 1 and 3) to elicit user feedback on our prototype exergame system, at various stages of the development process. At both workshops, participants were assigned to small groups of 3 or 4 to allow everyone to contribute to the discussions [38]. At the Workshop 2, physiotherapists were placed into a separate group from the senior groups, as we were interested in stakeholder opinions from different perspectives, without any influences from one group on the other. Each group of participants had a facilitator, who asked questions and guided the discussions, and a note taker, who noted the participants’ responses on the various topics. Ethics approval was obtained for each of the phases of Study 1 through: the NHS (Phase 1) and the researchers’ university (Phase 2 & 3). The interview and design workshop data (mostly qualitative) were analyzed using thematic coding, by two members of the research team, and verified by an additional individual who was not directly involved in the study. Direct participant quotes were also extracted and are stated in this paper to support the emergent themes from the various studies. In reporting the findings from the various studies, we use the letters ‘PT’ to represent physiotherapist comments (e.g. PT1, PT2, etc.) and ‘SN’ for seniors.

4.2 Phase 1: Design Workshop 1

We invited six participants who took part in our previous 12-week study (mean age = 76 years; 4 females, 2 males) to the first design workshop (Workshop 1); the participants were all over the age of 65 and had previously fallen at least once in the 12 months prior to the study. They were initially recruited from the UK National Health Service (NHS) falls group therapy classes. At the design workshop they discussed their experiences with the prototype exergame system, described in our previous work (which at that time did not explicitly show progress). The participants also discussed their preferences for tracking rehabilitation progress, either with or without the exergame system.

4.2.1 Summary of Findings (Phase 1)

All of the participants considered the ability to track progress essential to maintaining confidence and independence during home rehabilitation. The participants, who had also used the booklet, responded that there are a number of ways in which progress could be tracked without technology: a) writing down the number of repetitions achieved; b) keeping a diary; c) recording how well each exercise was done, and d) marking one’s emotions. The following participant comments support these findings:

- SN1: “You could write down the number of repetitions that you have achieved.”
- SN2: “...keeping track of how well you are able to do the exercises.”
- SN3: “...marking down how you feel on that day.”

The participants also expressed a desire to view progress on a scale of relative exercise performance, as commented by Participants SN4: “I would like to see if I am doing an exercise better, or worse, than previously” and SN6: “...on a scale of maybe 0 [meaning ‘not good’] to 10 [meaning ‘perfect’].” The participants noted that progress tracking is important, and they offered suggestions on how this could be achieved with, and without, the exergame system. One interesting finding was the feedback on tracking emotions, which, while not directly related to physical performance, could have an effect on whether people exercise or not. With the participant feedback from Workshop 1 we had an introductory-level understanding of the requirements for the design of progress tracking through our exergame system.
4.3 Phase 2: Interviews with Physiotherapists

Through participant feedback, in Workshop 1, and drawing inspiration from previous work [3] to ensure a minimalist interface, we created a prototype progress chart (Fig. 4) that showed scores achieved in one game for the *Sit to Stand* exercise (this exercise is shown in Fig. 1). There are existing designs, on progress, which have been applied in numerous game systems using a variety of ways to represent progress and achievements, e.g. Wii Sports, Kinect Sports, etc. However such games do not focus on musculoskeletal rehabilitation, whereas the systems that inspired our designs, e.g. the total knee replacement system in [3] (while not games) have proven effective at communicating functional progress since they focus precisely on quality of movement. Furthermore, this representation is just one possible way, justified by participant feedback on their willingness to compare progress at different times (hence the chart method).

We interviewed 6 physiotherapists, individually, who all had over 5 years experience within the NHS falls service. Our prototype chart was shown to the physiotherapists, as both an image and an animated movie, using bars that gradually increased (in length) over time. Colors were used to highlight the week with the highest scores – also to show the score to beat. The physiotherapists were asked to provide feedback on using such a chart to communicate rehabilitation progress to seniors who would use the system in the home.

![Fig. 4. First progress chart prototype for the exergame system.](image)

4.3.1 Summary of Findings (Phase 2)

When using the system, each exergame ended when the player completed the repetitions required, and scores were directly related to exercise performance (Fig. 2 and Fig. 3). Participant PT1 felt that this was a useful benefit of the system, as evidenced by their comment: “Mapping scores in games to the achievements and goals is a good idea.” There was also a desire to give users the ability to progress to a more difficult version of the exergames. On this point, PT2 added: “It would be nice to have the ability to get a certain number [of in-game items]; then they can progress to more difficult.” Regarding the chart (Fig. 4), the physiotherapists highlighted the potential of using it for home rehabilitation, as evidenced by the comments by Participants P3: “If you tell patients that they are getting better, they take your word for it, but it is hard to convince people; with this [progress chart] they would be able to see improvement for themselves” and PT4: “They [seniors] don’t notice progression on a day-by-day basis; with the technology, they can actually see this progress.” There were physiotherapist comments on making the chart livelier, by adding characters, from the various games, on their respective progress charts – Participant PT2: “…have the [game character] there on the chart to make it more pleasing.” However, the physiotherapists stressed simplicity, in aesthetics, to reduce possible visual overload. To achieve this, and still maintain a sense of fun, Participant PT3 suggested using ‘smileys’ to communicate meaning in the scores: “…maybe use happy and sad faces to show how well they did.”

One important suggestion was the inclusion of goals, and goal setting, for a future iteration of the exergame system. One physiotherapist commented that progress could also be viewed in terms of achieving personal

goals. However, others stated that goals outside the scope of exercise are specific to each individual; therefore, it could be a complicated process implementing such a feature into the exergame system. Consequently goals should be based on exercise and performance, instead of individual goals, as highlighted by Participants PT4: “Something related to goal setting would be great; [the goals] might change but they are personal” and PT2: “goals [that people set] do not necessarily relate to the exercises themselves, so it could get complicated; with goal setting, it needs to be relevant to exercise.”

The findings confirmed that consistency, performance and frequency, in performing exercise, contribute to progress. Through a prototype, the physiotherapists were all in agreement that a dynamic chart could effectively communicate rehabilitation progress, and they offered recommendations for how this could be displayed. Furthermore, we learned about progression in falls rehabilitation in the home, that seniors should decide when they could attempt a more difficult version of the exercises, to demonstrate progress.

4.4 Phase 3: Design Workshop 2

From the feedback in the first 2 phases of Study 1, the following points were considered necessary to communicating rehabilitation progress:

- It is important to track exercise frequency (number of exercises completed) and performance (scores achieved in games) over a period of time.
- Goal setting is important, but individual goal setting could be complicated, and rehabilitation goals should be related to exercise frequency and performance.

In the final phase we held another design workshop, with mixed stakeholders – physiotherapists and seniors – to evaluate new prototype concepts to deliver the desired functionalities for progress communication.

4.4.1 Prototype Redesigns

First we created 2 similar concepts for progress tracking, showing: a) number of exercises completed or frequency of exercise (Fig. 5 left), and b) scores achieved in each game or performance (Fig. 5 right), over several weeks. Scores in performance, i.e. how well the users performed at each individual game, were expressed using the following grade system to denote percentage achievement: ‘A+’ (100%), ‘A’ (80 – 99%), ‘B’ (60 – 79%), ‘C’ (40 – 59%), ‘D’ (20 – 39%) and E (0 – 19%). Based on stakeholder feedback from Phases 1 and 2, the new prototype charts used a point system to express value, instead of the previous bar chart system (Fig. 4), with ‘smileys’ denoting performance level. We included the smileys, a suggestion from a physiotherapist in Phase 2, as a concept to elicit stakeholder responses to the idea of quantifying exercise performance and frequency using a high level method for conveying emotion – as suggested in Phase 1.

![Fig. 5. Second progress chart prototypes: exercise frequency (left) and grades achieved (right).](image-url)
Drawing on the previous work of [3] as a starting point, a pseudo traffic light color system was also used to categorize the values in both charts. We however used a rainbow-style gradient to allow for a wider range of performance from worst to best – red, orange, yellow, green and blue, to detect more subtle improvements in performance. The progress chart prototypes were designed to be similar in appearance to maintain consistency in design, highlighting the necessary progress metrics.

4.4.2 Goal Tracking using Medals

To address goal tracking, through the exergame system, we introduced the concept of milestones, using medals. Our medals (gold, silver and bronze) represented achievements in terms of both performance and frequency. Medals are used in sports (e.g. the Olympics) and commercial video games, e.g. Wii Sports, and these games provided inspiration for our medal system; however, in our case, the medals were directly related to our 2 metrics of progress. Five medal concepts were shown to the participants; these are detailed in Table 3.

Table 3. Medal concepts based on falls rehabilitation

<table>
<thead>
<tr>
<th>Medal name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High scorer (Performance)</td>
<td>Achieve at least a ‘B’ grade (60% score) in every game.</td>
</tr>
<tr>
<td>Marathon (Frequency)</td>
<td>Complete 100 exercises in total.</td>
</tr>
<tr>
<td>Perfectionist (Performance)</td>
<td>Achieve an ‘A’ (80%) or ‘A+’ (100%) grade in every game.</td>
</tr>
<tr>
<td>Completionist (Frequency)</td>
<td>Complete each game at least 3 times a week, for 12 weeks (minimum standard care).</td>
</tr>
<tr>
<td>Master (Frequency)</td>
<td>Complete each game at least 5 times a week, for 12 weeks.</td>
</tr>
</tbody>
</table>

By achieving the relevant requirements (highlighted in Table 3), users could unlock the various medals (Fig. 6). Even if users had not unlocked certain medals, they could still see the achievement requirements by highlighting the medals using the relevant keyboard key (numerical keys 1 – 5). Progression in exercise was also discussed at Workshop 2. In particular, we wanted to elicit stakeholder feedback on how they preferred to deal with progression (e.g. how difficult the exercises should be and whether – and when – they should be able to change the difficulty) when using the exergame system in a home rehabilitation scenario.

![Fig. 6. Medal prototype screen showing locked and achieved (or unlocked) medals.](image)

4.4.3 Participants and Recruitment

Eleven seniors (6 females, 5 males and not the same participants as in Phase 1) and 6 physiotherapists (5 females, 1 male and not the same physiotherapists from the Phase 2 interviews) participated in the workshop. We recruited the physiotherapists from the NHSGGC falls service and the seniors from a local housing association. At the workshop, there was 1 group of physiotherapists and 3 groups of seniors. Data were collected...
in the same manner as in Phase 1 (Workshop 1) with one facilitator and one note taker per group. All, but one, of the seniors had done rehabilitation exercise in some form, either through a class or using a booklet. Similar to Phase 1, the seniors were identified as at high risk of falling, by having multiple risk factors for falls [31,33]: over the age of 65 (mean age = 78) and had fallen at least once in the prior 12 months. The workshop enabled the stakeholders to discuss a wide variety of functions of the exergame system, including progress in falls rehabilitation. However, for relevance to this paper, we will only discuss findings on progress and rehabilitation goals (medals).

4.4.4 Summary of Findings (Phase 3)
The participants (seniors and physiotherapists) were first asked to discuss how progress is managed in current care. The seniors responded that they relied on memory, as they are not given anything to help them track their progress, as highlighted by Participants SN1: “Progress is something that you would feel as you carry out the exercises in a regular manner” and SN2: “Well, you try to remember what you did already and what you need to do; you have to remember that.” The physiotherapists confirmed that they do not monitor progress when seniors are doing these exercises at home, as commented by Participant PT1: “[Progress] is not tracked; we just ask patients how they are getting on.”

Progress: The participants were then shown the new prototype concepts on progress – one highlighting exercise frequency (Fig. 5) and a similar one showing exergame system (as grades = ‘A+', A, B, C, D & E). The participants were then asked to comment on the aesthetics and usefulness of these functions. Both the seniors and the physiotherapists responded positively to the concepts, stating that they thought they would be effective at communicating the important metrics of progress. For instance PT3 said: “I like that you can show number of exercises as charts” and SN3 commented: “The [progress chart] seems to be instant, you get the message that it is trying to represent.” The stakeholders liked the idea of using colors to convey performance through the charts; however they were not so enthusiastic on the use of ‘smileys’ for the same purpose, evidenced by the comments by Participants SN4: “…it looks infantile or childish; [it] could be better without the smileys”, PT2: “I like the progress chart; lose the smileys, but keep the grades” and PT4: “…the smiley faces are too patronizing.” These responses were interesting in the sense that a physiotherapist in Phase 2 suggested the use of smileys, at a time when they were not able to view them in a physical prototype. However, with a physical prototype, participants at the second workshop had a more negative opinion regarding the use of smileys to represent the level of progress. None of the participants at the second workshop were particularly positive on the addition of the smileys; hence we, as the designers, did not feel it necessary to include them in the next prototype.

Medals: The concept on medals (Fig. 6) was also shown to the participants in their various workshop groups. The medals were also found to be a useful mechanism, by all of the participants, to track exercise goals and achievements (in terms of performance and frequency) and also to motivate people to exercise more; this finding is supported by the following participant comments:

- SN5: “Although the main motivation to do exercises should come from within you, but these medals would definitely increase your motivation.”
- SN3: “Yes, it is a good idea; we all like to have a medal.”
- SN6: “The medals would encourage [people] to exercises.”
- PT6: “…the [medals] would definitely motivate the patients to exercise more.”

Progression: Both the seniors and the physiotherapists agreed that seniors should be able, and be encouraged, to decide when to attempt higher difficulty levels in exercise. On this point, Participant PT4 noted: “When you think of the dreaded [standard care] booklet, there is no progression, and you need that progression in exercise...” while Participant PT3 commented: “The games can be made more difficult by increasing the repetitions or the duration of hold.” Participant SN4 stated that they would appreciate such a feature, as it would facilitate some level of control and self management of rehabilitation (supporting previous work on rehabilitation [4]): “I like that idea; I want to be able to do that as you are expected to do this on your own and the exercise would get too easy after a while.” The findings from Workshop 2 supported those from Phases 1
and 2 of the requirements gathering study (Study 1). The prototype concepts on progress and medals were found to be useful for tracking progress and long-term rehabilitation goals.

4.5 Pre-Trial Modifications to the Design of the System

Based on the findings, from all 3 phases of Study 1, we made changes to the design of the next prototype of the exergame system; these are highlighted in this section.

- The two progress charts were implemented in the exergame system: one recorded the number of exercises completed (frequency), while the second one recorded achieved grades (performance); both charts (shown in Fig. 7) could be accessed at any time while using the system. The smileys were replaced with plain dots, based on the stakeholder concerns raised in Phase 3; however the colors were maintained (red, orange, yellow, green, blue) to indicate performance since they were well received.
- Players could unlock the medals (as highlighted in Table 3 and Fig. 6) indicating various milestones in frequency and performance; these could be accessed at any time while using the exergame system.
- Three levels of difficulty were included for progression: easy, normal and difficult, inspired by existing commercial games that adopt these 3 difficulty settings. The difficulty levels varied by the number of repetitions and amount of time required to hold a limb in a particular position. For instance, in the Fire Rescue game (Fig. 2), players could rescue 10 characters under the normal setting and progress to 15 in the difficult setting. Furthermore the player was required to hold the leg for up to 5 seconds, instead of 3, under the difficult setting. Players could choose a different difficulty level at any point while using the system.

5 STUDY 2: FIELD STUDY

Following Study 1, and after implementing the design changes (in 4.5), we conducted a 2-month user study to evaluate the use of the revised exergame system in the home. In this study, 16 seniors (10 females, 6 males) aged between 65 and 85 years of age (median = 77, SD = 6.1) were recruited; these were not the same participants recruited in Study 1 (phases 1 and 3). The seniors were recruited from local housing associations, using flyers, and were at high risk of falling, as described in Study 1 (65+ years of age, 1 fall or more in the last 12 months). Ethics approval was obtained through the researchers’ university. The participants used the exergame system individually in their homes, with no external support, throughout the study; this was done to
evaluate the system in the field, i.e. in an unassisted home rehabilitation context – as is the case with standard rehabilitation care. With the exergame system, the participants were able to perform the following activities at any time they wanted: a) play any of the exergames, b) check their progress using both the frequency and performance charts (Fig. 7), c) check medals that they had unlocked in accordance with the various set rehabilitation goals/ milestones (Table 3, Fig. 6), and d) change the difficulty level of the exergames. Results on the usefulness and acceptance of the system, with regard to progress, medals and progression were collected at the end of the study using both quantitative (Likert scales) and qualitative (questionnaire and an interview) methods; these results are presented together to maintain consistency in reporting.

Note: the purpose of the home study was to investigate much more than what is reported in this paper, including the use of the exergames; however we report only on user feedback on progress tracking, medals and progression, to maintain a consistent narrative and remain within the scope of the work reported on in this paper.

5.1 Data Collection and Analysis

Similar to the Study 1, the data obtained in Study 2 (mostly qualitative, because we were interested in the participants' opinions regarding the progress tracking mechanics of the exergame system) were analyzed using thematic coding, by two members of the research team, and verified by an additional individual who was not directly involved in the study. Direct participants quotes are used, where necessary, to support the study findings; again participants are quoted using the prefix ‘SN’ to maintain consistency in reporting.

5.2 Findings

Table 4 shows the results from the Likert scales on usefulness of the progress charts, medals and progression mechanics, as well as acceptance of these features – median and interquartile range (IQR). Usefulness was rated on a 5-point Likert scale of 1 (not very useful) to 5 (very useful). Acceptance was rated on a 5-point Likert scale of 1 (not very likely) to 5 (very likely) in terms of how likely the participants were to continue to use these features – if they used the exergame system past the study period.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Median</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progress charts</td>
<td>4</td>
<td>1.25</td>
</tr>
<tr>
<td>Medals</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Progression (difficulty)</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Acceptance</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

5.2.1 Usefulness (Tracking Rehabilitation Progress)

The participants were asked to rate how useful they felt both progress charts were at communicating rehabilitation progress in falls therapy over time. The results were positive for progress tracking using either the performance or frequency charts (Table 4). Regarding the preferred method of viewing progress, 7 (44%) of the 16 participants preferred using both methods. Five (31%) participants preferred viewing progress in terms of performance (game scores/ grades) while 4 (25%) preferred to view progress in terms of frequency (exercises completed). The following participants’ comments provide more insight into the usefulness, and preferred methods, of tracking progress.

• SN12: "...I could keep track of which exercises I’d done, and when, that is helpful; I tried to do more than the average [of 3 sessions per week]."
• SN14: "It's exciting to see the score chart at the end; it makes you want to try again."

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SN3: “Oh yes [the charts] were interesting; I like to keep active, and I found it good for helping me keep track of both [frequency and performance].”
SN6: “I prefer both [charts]; I think it is important to see both as they talk about two different things, which are important in different ways.”

5.2.2 Usefulness (Medals)
The participants were asked to rate how useful they felt the medals were for tracking milestones over time; the results were also positive (Table 4). The participants’ comments reveal that the medals helped them to accomplish exercise goals and establish some discipline around integrating exercise into their daily routine, as evidenced by the comments by SN15: “[Medals] allowed me to set an agenda and find time to do the exercises” and SN4: “That’s what I like best [about the system]; it helps if you have the likes of this, as you have some exercise goals to accomplish.”

5.2.3 Results on Difficulty Levels (Progression)
The participants were asked to rate how useful they considered the ability to change the difficulty setting for the exercises; this system function was rated highly, with a median of 5 out of 5 (Table 4). We also tracked how many times the participants changed the game difficulty using the system. All of the participants started with the normal setting and were told that they could change the difficulty whenever they felt like it. Most of the participants did not change the setting over the 2 months. Two of the participants changed to the difficult setting after 3, and 5, weeks of the study, citing a need for an increased challenge, as evidenced by the comment by SN12: “I want all of the fruits [in-game items], so I try to prove to myself that I can get them all.” Most of the participants did not feel the need to change the difficulty; however they appreciated having the option, as commented by SN3: “I didn’t change [the difficulty setting], I was happy with mine, but I want to be able to change if I want.”

5.2.4 Results on Acceptance
Although the participants’ comments on the various progress communication methods show high levels of acceptance, we also explicitly evaluated acceptance of these features using a Likert scale. The findings were positive, with 11 out of 16 participants giving a rating above average (3 – no opinion, 4 – likely and 5 – very likely to use the progress mechanics) and 1 person rating below average, suggesting positive acceptance.

6 DISCUSSION
Through research questions Q1 and Q2, we set out to investigate stakeholder opinions on: a) progress in falls rehabilitation, and b) how progress can be effectively communicated through exergame technologies.

6.1 Answering the Research Questions
Q1 asks: “What are the opinions of the main stakeholders (physiotherapists and seniors) on progress in falls rehabilitation?” Progress, according to the physiotherapists, can be defined in terms of physical function, or in terms of goals, both functional and personal. Functional goals comprise of metrics directly related to effective recovery. The literature defines metrics of physical function, in musculoskeletal rehabilitation, in terms of quality of movement (QOM), which consists of range and pace of movement as well as the number of repetitions achieved in each exercise and the number of exercise done in the long term [3,34]. In home-based falls rehabilitation, seniors are required to exercise in accordance with this QOM. Indeed physiotherapists recommend that rehabilitation exercises should be done at least 3 times a week for a period of 12 weeks [37]; this assures users of the amount of therapy (approximately 50 hours [31]) necessary to reduce their risk of falling. Our exergames promote effective QOM through active play, since achieving scores (in the various exergames) is directly related to QOM. By observing rehabilitation progress, through the progress charts (Fig. 7) and medals (Fig. 6), the seniors felt confident that the system catered to their needs regarding assurance of therapy. This confidence is considered paramount to their maintaining a long-term interest in exercise. Since
falls rehabilitation in the home is mostly unsupervised, the stakeholders considered progress tracking (using the charts, medals and progression mechanics) an effective way to self-manage their rehabilitation. This potentially reduces costs to healthcare services (on patient visits) and encourages seniors to take responsibility for their health and recovery when possible.

Q2 asks: “How can rehabilitation progress be effectively communicated to seniors, undertaking unassisted falls rehabilitation in the home, using an exergame system?” Personal goals were deemed too varied to be accommodated by technology, and these were best left to the seniors to track on a personal level. Progress in physical function can be shown effectively, through technology, as it is absolutely based on changes in balance and strength, over time. The important metrics of progress include maintenance of, or improvements in, exercise frequency (number of exercises) and performance (QOM). Our stakeholders considered the progress charts, in the exergame system, to be effective, and useful, at communicating these metrics during home rehabilitation. They also considered the medals useful for communicating long-term functional rehabilitation goals and establishing some sort of routine, and discipline, around exercise.

6.2 Lessons Learned and Opportunities for Design

There are several lessons learned, throughout our studies, on the role of progress tracking in exergame systems and the implications for the design of such mechanics in exergame systems. First, personal goals are often set by seniors who are at risk of falling; such goals may include: walking up the stairs with ease, being able to walk for up to 100 meters and being able to do the gardening. Since these personal goals can be difficult to track using technology, it is advisable to track objective outcomes that are directly relevant to physical therapy. We recommend that there is focus on these important outcomes and metrics in the design of exergame systems. The ability to objectively measure physical therapy progress in the home, using our system, was considered essential to assuring seniors of recovery, and this motivated them to continue using the system over the long term. Our stakeholders felt that communicating long-term milestones, through medals, is a great way to ensure achievement in therapy through exergames. To maximize effectiveness medals should be tailored to define milestones in both QOM (e.g. achieve consistent high scores or grades) and exercise frequency (e.g. do 100 exercises or 3 sessions per week for 12 weeks) – the two main components of falls rehabilitation therapy.

Secondly, progression is a natural component of physical rehabilitation. At certain points during the rehabilitation process, it is advisable for seniors to progress to a higher level of difficulty in tasks [9], for physical therapy to be effective. Rehabilitation technologies, including exergame systems, should allow for this progression either by authority of a physiotherapist (at the start of rehabilitation) or the end user (at subsequent points based on physical ability). In falls and other areas of movement therapy, such as the knee [2], seniors are expected to engage in unsupervised home rehabilitation; thus exergame systems (and rehabilitation technologies in general) should allow for the ability to choose varying difficulty levels [9]. This could further empower the users to manage their rehabilitation and eventual recovery. Opportunities also exist around automating changes in difficulty based on the performance and progress of seniors during rehabilitation. The main challenge in this regard, from a therapy perspective, is that a physiotherapist should make this decision for the seniors, based on their professional opinion. It would be interesting to investigate, in future work, how rehabilitation systems can automatically make such decisions, e.g. through machine learning algorithms and physiotherapist input. In the mean time we suggest that rehabilitation systems should, at least, suggest changing difficulty, and it will be interesting to note how the users respond to these suggestions in an unsupervised rehabilitation scenario.

Thirdly, rehabilitation can have numerous outcomes and metrics that define effective recovery. In falls therapy we recommend that QOM be embedded in exergame mechanics for maximum therapeutic effect. This ensures that game scores deliver an accurate representation of movement quality. The best way to achieve this is by involving stakeholders in the design of exergames [2,38]. Our stakeholders often preferred one method of viewing progress to the other (e.g. performance vs. frequency); however, from our home study findings, the majority preferred to view both of these metrics. They felt that all of the rehabilitation metrics, defined by the physiotherapists, are important and provide a more complete picture of progress. Thus, we recommend that as many vital metrics of recovery are considered as is necessary, as preferences may vary between users.
6.3 Limitations
Our work focuses on physical rehabilitation, and in particular, falls. There are other factors specific to areas such as: stroke and pain in knee therapy that need to be explored, in further research, to understand how progress in those areas can be effectively measured and communicated to seniors through exergame technologies. However, these factors are beyond the scope of this work in that we provide a starting point for how progress can be communicated in the movement (purely physical) rehabilitation space. Another limitation is our work is that Study 2 (the field study) was done at the lower end of the long-term rehabilitation spectrum (2 months). Further work is recommended to investigate how seniors will react to progress tracking, through exergame technologies, over the longer term (e.g. 6 months [24]).

7 CONCLUSIONS
This paper describes the evaluation of components of an exergame system to communicate rehabilitation progress to seniors at risk of falling during physical rehabilitation in the home. We focus on progress communication because it is not clear from the existing literature how this should be designed, from the stakeholder’s point of view, in home-based rehabilitation systems. In exergame systems, there is a greater challenge due to the focus on fun, rather than movement quality, as well as a certain level of abstraction in visuals compared to movement visualization systems that explicitly show range of movement in terms of joint angles. The assurance of progress is essential to improving confidence in the effectiveness of rehabilitation exercise (especially in the home); therefore we set out to investigate how exergame systems can effectively communicate progress to seniors undertaking home rehabilitation. In this work we found that progress in falls rehabilitation, determined through exercise frequency (number of exercises) and performance (QOM), is important to assuring seniors of recovery, and it is vital to observe both of these metrics to provide a complete picture of progress. We also found that charts and medals, such as are described in this work, are an effective way to show improvements in these important metrics for effective recovery, as well as setting achievement milestones over time in physical therapy. In addition, we investigated the importance of difficulty levels, in exergames, showing progression over time; this progression is an essential component of physical rehabilitation, for which we encourage further work. This work adds to our previous work [36,37,38] by providing evidence, which suggests that our progress mechanics could prove useful in an attempt to encourage the prolonged use of exergame systems in the home – consequently leading to potential improvements in physical function as well.

Finally, through addressing our research questions, we highlight implications for the design of mechanics in exergame systems to accommodate for effective progress tracking. Due to similarities, in physical therapy and outcomes, we posit that the findings and discussions in this paper can, to some extent, be generalized to other areas of musculoskeletal rehabilitation, e.g. stroke, hip and knee. However, further work is needed to determine how this can be done effectively in such scenarios.

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