# Design and Evaluation of a Fall Prevention Multiplayer Game for Senior Care Centres

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**Abstract.** Preventing falls is extremely important today as people live long sedentary lives. Fall prevention platforms can help, by stimulating seniors to perform exercises that improve balance and muscular strength. However, existing platforms for fall prevention mostly target individual users exercising at home. This paper describes the design and evaluation of a multi-player fall prevention game platform, FallSensing Games, to be used in senior care centers. The game design was inspired by the Otago Exercise Programme and the evaluation focused on biomechanical parameters, game experience, and technology acceptance. Results showed that the game was easy to follow, that seniors performed exercises correctly, and that the game integrated well with the activities of the senior care centers. Lessons learned from this project may inspire the development of similar platforms, and, in this way, support group exercise practices at senior care centers.

**Keywords:** Serious games · Exergames · Multiplayer games
Fall prevention · Older adults · Wearable devices

## 1 Introduction

Falling is normal and can happen to everyone, but, as people age, falls can become dangerous. One often hears about seniors who fall and need to be admitted to the hospital or become unable to pursue their everyday activities. Falls have a multi-factorial origin being mostly related to biological, behavioural, and environmental factors. Biological factors include characteristics of an individual such as age, gender, functional ability, gait disturbances, and co-morbidity associated with chronic conditions. Environmental and behavioural factors include indoor and outdoor hazards like loose rugs, stairs, uneven pavements, or insufficient lightning, inappropriate footwear, excess of medication, lack of exercise, and sedentary lifestyle [1,6,13]. Most risk factors can be amendable, with the implementation of alternative daily choices and physical exercise. Specially for


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seniors, promoting physical activity and an active lifestyle is essential to postpone frailty and physical vulnerability [1,13].

Several solutions have been proposed to prevent falls using serious games [11,12,17,18,23]. However, the majority of existing solutions were designed to be used individually by a senior at home. Solutions to be used at home may work in some situations, but they disregard the social component of exercising practices, often present in senior care centres. Moreover, designing technologies for promoting and supporting exercise in senior care centres may contribute to the active and healthy ageing of the seniors in those institutions.

This paper describes a fall prevention technological solution based on an interactive (exer)game. Players have a TV screen in front of them displaying a game and wear a strap on the lower limbs which contains an inertial measurement unit (IMU). This wearable device enables movement identification and characterization in real time, triggering actions in the game, and, ultimately, allowing an analysis of each participant's performance. The included exercises are a subset of a validated fall prevention exercise plan - the Otago Exercise Programme (OEP) [4] - used to promote mobility, muscular strength, and balance. The exercises are presented through a series of interactive mini-games[1] specially designed for groups (up to 6 persons) playing in senior care centres.

The developed solution was tested in three field trials in senior care centres. Our field work draws on interviews, questionnaires, and observation in senior care centres, where a total of 37 seniors used the system. The analysis focused on the usability, acceptance, and appropriation of the system in the centre. We also reflect on the three lessons learned, namely: the active role of the care worker in promoting the engagement with the game, the competition between players during the games, and the overall acceptance of the games. Lastly, we report the analysis of the exercise-related metrics extracted from the wearable devices, which enabled the evaluation of in-game performance analysis.

The remaining of the paper is organised as follows. Section 2 describes the prior art in games for fall prevention. Section 3 details the design of the fall prevention solution. Section 4 describes the field trials conducted, and Sect. 5 reports the resulting main findings. Section 6 discusses this work and Sect. 7 highlights the main conclusions and opportunities for future work.

## 2 Related Work

Exercising through video games, or playing exergames, is a recent concept that combines the fun component of playing a video game and physical exercising [7,21]. It is generally acknowledged that exercise delivered through exergames is more acceptable by seniors than more clinical exercise strategies [7,17,18,21]. Exergames are promising for different rehabilitation purposes, including regaining functional ability [7,17], improving mobility [7,17,18], preventing cognitive decline [7], and promoting social inclusion [7,18]. However, there is a lack of validated solutions, specially regarding the adherence and engagement of seniors [7].

[1] Mini-games are small games that are contained inside a larger game plot.

Examples of exergames in the market include Dance Dance Revolution (DDR), Sony Playstation II Eye Toy, and Nintendo Wii Sports. These particular platforms have been tested with seniors in short term pilots, obtaining interesting results in terms of users' acceptance [7,15,22]. However, most of these solutions were originally designed for entertainment and recreation purposes and thus do not present a strong effectiveness [15,21] as is expected from fall prevention interventions. Moreover, overloaded interfaces, small fonts, game complexity, and lack of personalized goals can hinder these platforms from achieving consistent engagement when used by seniors [7,11,21].

There are some exergames in the market that were specifically designed for seniors. Examples include Corehab [8], Rehametrics [16], 3D Tutor [10], or SilverFit 3D [19]. These solutions target rehabilitation rather than fall prevention and were designed to be used by individuals at home or by healthcare providers at clinics. The only example we could find where seniors were expected to use the system in a senior care center was in PEPE [20], a robot developed to stimulate physical activity, with whom seniors play individually in front of the group.

Specifically designed to prevent falls of seniors we find two prototypes in the literature: FCC-Exergames [17] and Dance Don't Fall [18]. Both solutions were designed to be used by seniors at home. FCC-Exergames is an individual game and Dance Don't Fall enables two seniors to play together at home. Nevertheless, systematic reviews report a discrepancy between the number of available solutions that target exercising in groups compared to exercising alone [21]. With this context in mind we present a novel solution, the FallSensing games, designed to be used at senior care centres to reinforce group exercise practices for fall prevention and promote social interactions among seniors.

## 3 FallSensing Games

The FallSensing games include three mini-games to be played by two teams, with up to three players each, competing against each other, alternately. Players wear one wearable inertial sensor to track the movement execution. This sensor can be placed in the thigh, on the ankle, or on the top of the foot, depending on the game. Each game has its own rules and gameplay experience depending on the requested movement, which is based on a set of OEP [4] exercises. The movements to be executed are recurrently explained to promote their safe performance. Movement data is evaluated by the system to animate the avatar.

The OEP is a set of leg muscle strengthening and balance retraining exercises, that has shown to be effective in reducing by 35% the number of falls. Given this evidence for fall prevention, this programme was selected to be implemented as a set of mini-games. Strengthening exercises focus on major lower limb muscles. Balance retraining exercises focus on reinforcing body balance recovery using lower body exercises. The combination of OEP exercises into mini-games aimed to group exercises with the same sensor position on the body, to avoid sensor's re-position, and to combine exercises that reinforced the same group of muscles.

The game was designed around the Antarctic theme and the main actors are penguins. We chose to use penguins as avatars because they can be modelled to perform the required exercises, while keeping a fun factor for users. There are three mini-games inside the main screen. Each mini-game combines up to three physical exercises. In choosing which games to pair we minimized the changes in positioning the wearable (to sustain the gameplay), we balanced the relative effort of exercises, and considered the distance among the players and between the players and the display.

There are two types of users in the system: players and administrator. Players are seniors who wear the sensor on the limbs and perform exercises. The game administrator can also be a senior, but in most cases will be a care worker from the institution who works with the seniors. Game administrators start the system on a computer and select the players who will play for each team.

### 3.1 Requirements

Based on previous research on exergames for seniors and TV user interfaces for this audience [3,11,12] we identified the following game design requirements:

1. **The game administrator should be able to select players or enter new players that are not in the system,** to enable different people in the institution to play (and be individually monitored).
2. **The system should monitor the execution of movements continuously and reflect it in real-time through the avatars' animations.** Immersion in the game and identification with the characters depends on a clear alignment of the players' movements and the avatars' actions.
3. **Exercise instructions should be clear and easy to follow.** Players need to understand which movement to perform, when to do it, and how many times to repeat it, while being immersed in the game. In this regard, it should be noted that the speed of some exercises animations were reduced to better fit the playing rhythms of seniors.
4. **The user interface should be usable at a distance.** Seniors need to read the text in the interface comfortably on a distant TV, thus appropriate font-type and font-size need to be considered. Used graphics should also have appropriate dimensions and contrast to be understood at a distance.
5. **The visual feedback of the performance should be complemented with sounds.** Similar to the previous requirement, this one focuses on addressing common characteristics that arise with age, such as eyesight limitations and decreased cognitive processing speed. Auditory feedback can complement the game experience by helping players to notice changes in the game. Moreover, sounds and music increase the fun factor of the system.

### 3.2 Mini-Games

The following description explains the three mini-games, respectively, regarding the exercises to be performed, the position of the inertial sensor, and their respective goals (avatars vs player). It is worth noting that the penguins (i.e., avatars) are differentiated by the colour of their clothes and accessories: blue, green, or yellow. Sensors are also coloured in the same scheme.

**Mini-game 1:** This game includes Knee Bends and Sit-to-Stand exercises, monitored with a sensor on the thigh. Penguins start a walk on the snow, and when they encounter lakes, users need to bend their knees to enable the penguins to jump over the lake (Fig. 1). If the exercise is performed incorrectly or out of tempo, the penguin falls into the lake, and the player looses some time. After jumping the lakes, each penguin needs to pick up with their beaks 10 fishes from a pile. To catch the fishes each player must do the exercise Sit-to-Stand properly; otherwise the penguins will not be able to catch all the fishes on time. The objective is to perform all activities (jump all the lakes and pick all the fishes) in the shortest time possible.

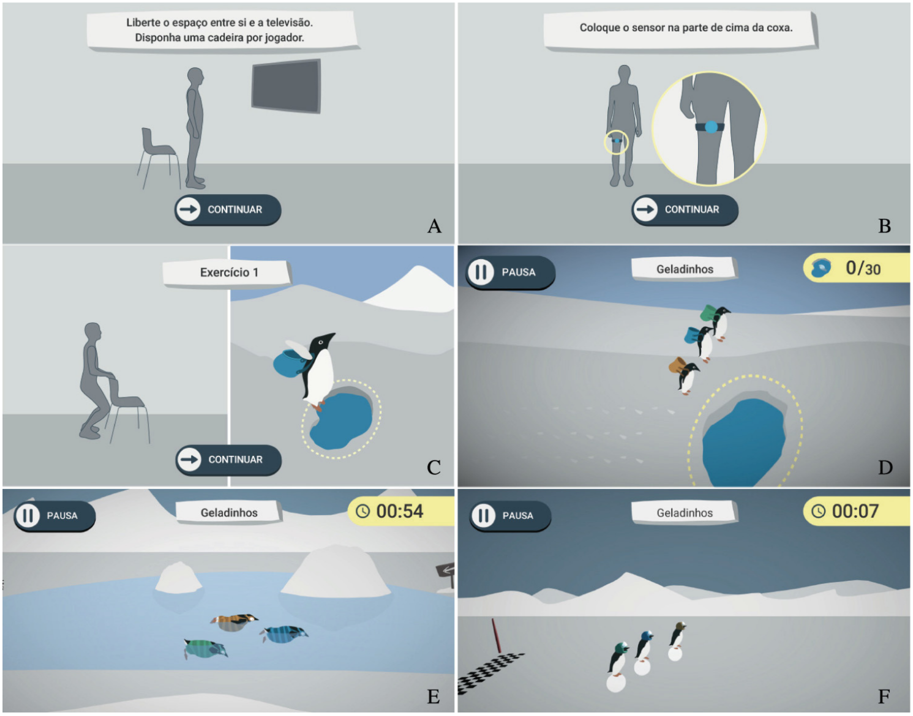


**Fig. 1.** A: space required to perform exercise; B: instructions to help fixing the sensor; C: exercise instructions to follow; D: Mini-game 1; E: Mini-game 2; F: Mini-game 3.

**Mini-game 2:** This game includes Lateral Hip Abduction (Side Hip), Frontal Knee Extension (Front Knee) and Backwards Knee Flexion (Back Knee) with the sensor on the ankle. The penguins have a big lake to swim but before entering in the lake they have to warm up, lifting laterally their left and right paw five times. To do it, each player must do the right and left Lateral Hip Abduction exercise five times. If the exercise is well done the penguins conclude the warm up and enter the lake. To start the breaststroke swimming each player must do the Frontal Knee Extension exercise to enable the penguin to swim forward (Fig. 1). Arriving to the end of the lake, the penguin will return doing the backstroke swimming movement; each player must do the Backwards Knee exercise for this action. If seniors perform the movement steadily and slowly, as instructed, the penguin swims faster, while if they perform exercises too fast or incorrectly, the penguin will go slowly. We added this time-related feature in the game because OEP recommends strength exercises to be performed slowly, i.e. 3 seconds for the ascendant phase and 5 seconds for the descending phase. Using this strategy, each player needs to do 10 repetitions to swim each side of the lake, otherwise, players need to perform even more repetitions to travel the same distance. Still, the objective of the game is to travel all the lake in the shortest time possible.

**Mini-game 3:** This game includes Calf and Toe Raises with sensors on top of the foot. The penguins have a path to run on top of a snowball. They have to roll the ball forward until the first target, without loosing their balance (Fig. 1). The players must do the Calf Raises exercise correctly to enable the penguins to move forward with the ball, otherwise the penguins will lose their balance and run slowly. After reaching the first target, the penguins have to do the backward path rolling backwards until the finish line. The players need to do the Toe Raises exercise effectively to accomplish this action, otherwise, and once again, the penguins will lose their balance and run slowly to the finish line. Similarly to Mini-game 2, a mechanism to control exercise execution speed was employed for this mini-game aiming for the slow execution of each exercise repetition. At least 5 exercise repetitions are needed in order to run each side of the course. Once more, the objective is still to cross the finish line in the shortest time possible.

## 4 Methods

To explore how participants used the developed solution, we organized three different field trials. During trials, we used semi-structured interviews, observations, and/or the System Usability Scale (SUS) [2]. The participants were presented with the FallSensing Games, that were explained to them prior to the execution of the mini-games. It was also explained the main goal of the games was to retrain fall prevention strategies. The first trial was conducted during an afternoon in a day-care centre with 21 seniors (19 female). Participants played a single game during the time we spent there. After the game sessions, every participant answered the Portuguese of the SUS questionnaire, and additionally participated in a short interview to understand the perceptions of the gaming experience (e.g., encountered difficulties, expected outcomes, hedonistic and utilitarian value expectations) with questions regarding acceptance, difficulties, obstacles, outcomes, and feelings during the game. The average age of this group was $80.3 \pm 8.05$ years old.

The second trial was conducted in a day-care centre with 10 female seniors. The participants played 3 mini-games twice a week for 3 weeks (6 sessions). On average, each session lasted half an hour. The average age of this group was $69.4 \pm 11.15$ years old. This group also attended gymnastics sessions in parallel to the fall prevention games. Only observations notes were taken during this trial.

The third trial was conducted in a nursing home with 6 female seniors. Participants engaged in 15 sessions, with an average duration of 20 min per session. The tests were performed twice a week, during 7 weeks. The average age of participants in this group was $83.5 \pm 8.22$ years old. This group also attended gymnastics sessions in parallel to the fall prevention sessions.

In the third trial, we also monitored the quality of the performed exercises. In particular, we compared the recognition of the exercises by the system with the evaluation of an external observer. An exercise repetition was only considered when the user started the desired movement, reached a minimum target joint angle, and returned to the initial orientation. Tracking changes in the orientation of the moving limb was performed by using data from the wearable sensor accelerometer and gyroscope (sampling frequency: 50 Hz) within a sensor-fusion based second order complementary filter [5,14]. This enabled the characterization of the whole movement including the collected metrics such as: (i) number of completed repetitions, (ii) maximum reached joint angle (range of motion), and (iii) repetition cycle duration. The target joint angle was previously defined according to the literature and with the help of a group of physiotherapists which took into account the advanced age of this group [9].

# 5 Results

## 5.1 Overall Experience with the Platform

The participants considered the games easy to understand and to play, despite their physical challenges. They indicated that the game interface clearly communicated the game objective, saying that "the games' screens always told them what to do, so they could easily accomplish the games' objectives". Most participants considered the games fun and they appreciated the penguins avatars as well. Placing the wearable devices on the body was considered difficult to be performed alone and the fact that sometimes the bracelet moved away from the right place and interfered with the games bothered them. While the majority of participants found the mini-games appropriate for their age, some elderly participants indicated that the game movements were too challenging (e.g., uncomfortable body movements, too fast) which interfered with their performance. One of the participants mentioned that he was not comfortable in getting up from the chair as fast as required by the game being played as a race. The majority of participants was comfortable with the text fonts, but a small number of participants said it was too small for them (Fig. 2).

Participants mentioned they would like to play the games again in the future, because it enabled them to exercise, play together, and pass time. Most of the participants referred they have a very inactive lifestyle and that solutions such as the one developed will provide them with opportunities to perform exercise.

**Fig. 2.** Seniors during field trial sessions.

A participant mentioned that *"It is so we can pass the time, instead of just being here talking to each other. It is a way of being entertained, a way to pass the time."*. Participants often commented that the games could contribute to training their memory. One participant commented that *"What would make me play, first, because I have to concentrate in what I am doing, and it is good for my brain. And because I like to play games on the computer [FallSensing games]."*.

Participants considered the interaction to be modern and enjoyed to interact with a "computer". They felt that playing the game was a way to get further informed about the latest technological developments, and also a way to learn about how to use novel technologies such as computers.

The SUS questionnaires conducted with 21 persons also confirmed the high usability of the system. The SUS global score of 80.12 characterises a highly usable and acceptable system.

**Table 1.** Extracted biomechanical metrics of playing FallSensing mini-games (MG).

| MG | Exercise | Nr. cycles | ROM (°) | Target ROM (°) | Cycle time (s) |
|---|---|---|---|---|---|
| MG 1 | Knee Bends | $3.08 \pm 1.83$ | $38.00 \pm 12.27$ | 15 | $2.04 \pm 0.99$ |
| | Sit to Stand | $4.14 \pm 4.12$ | n.d | - | $3.23 \pm 0.98$ |
| MG 2 | Side Hip | $5.16 \pm 0.44$ | $39.85 \pm 6.97$ | 15 | $1.58 \pm 0.76$ |
| | Knee Extension | $23.52 \pm 4.32$ | $73.11 \pm 12.77$ | 30 | $1.40 \pm 2.76$ |
| | Knee Flexion | $20.52 \pm 3.56$ | $81.20 \pm 13.31$ | 30 | $1.32 \pm 0.83$ |
| MG 3 | Calf Raises | $8.57 \pm 1.50$ | $24.12 \pm 7.04$ | 10 | $1.80 \pm 2.17$ |
| | Toe Raises | $7.08 \pm 1.78$ | $15.34 \pm 7.10$ | 10 | $1.63 \pm 2.49$ |

### 5.2 Movements Analysis

Besides providing an appropriate experience to seniors, the system was also able to accurately identify the performed movements (Table 1). All users could perceive and effectively execute the proper exercise movements to control the avatar in quite a satisfactory way, with the worst case being the execution of the 3 out of 10 correct Knee Bends during Mini-game 1. Moreover, this result may be related with the increased complexity of this exercise, because each player has to perform Knee Bends and coordinate their execution with the proximity to the lake; otherwise the penguin falls into the lake. If players fail to coordinate the timing, the repetition does not count and their avatar is slowed down. This mini-game feature was designed to instruct the user to perform the desired exercise and train the reaction time to a stimulus (i.e., approaching the lake).

As for the remaining mini-games, the number of detected repetitions was larger than the proposed values, as expected. The larger values are due to the designed game mechanism which penalizes the users who performed strength exercises performed too quickly. This mechanism was designed to simultaneously fulfil an OEP requirement and encourage users to perform the movements correctly and slowly without compromising the playful nature of the game. However, the mentioned mechanism did not work as effectively as expected, since in some cases, participants needed twice more repetitions than projected to finish the game. Moreover, this is corroborated by the fact that for practically all mini-games, the average cycle duration was almost always less than 2 seconds, instead of the expected 8 seconds reference value (3 and 5 seconds for ascending and descending movements phases, respectively). Executing more repetitions is not necessarily a problem, however it can lead to muscle fatigue and discourage seniors to play the game in the long term. Therefore, an alternative and more intuitive solution should be sought in order to fulfil this requirement.

Exercises' range of motion (ROM) was also evaluated using these mini-games being the obtained ROM results in agreement with proposed values for this age group, namely 45° for hip abduction, 70° for knee extension, 90° for knee flexion, 30° for plantar flexion, 20° for plantar dorsiflexion, and 40° for knee bending exercise [9]. Range of motion together with muscle strength can be an indicator of functional disability or an increased fall risk level on seniors. Thus, by targeting muscle weakness and movement ROM using this set of exergames, seniors can continuously improve their physical abilities and recover proper ROM.

### 5.3 Role of Care Workers During the Game

Our observations led us to conclude that external motivators such as care workers play a valuable role throughout the gaming process. Physiotherapists and social educators from the centre often provoked seniors to play the game and provided great incentive while seniors were playing. During the first session, seniors would be reluctant to try the system. Physiotherapists or social educators would start playing the game, with one or two people, and after a couple of minutes, almost everyone was standing around the game and looking forward to play it. Our initial expectation was that care workers would help in choosing players or register them in the system, but their role was much more prominent. They were initiating participation, stimulating team spirit, and motivating participants throughout the game to perform at their best.

### 5.4 Placement of Wearable Sensor

The placement of the wearable was problematic in some situations. Older women from Portugal frequently wear skirts and to position the sensor on the thigh they would have to raise the skirt in front of the group, or to go to a side room to place it. None of these options offers a great experience, and since participants might place the sensor quickly, data collection may be compromised as the sensors is not well attached to the body. Placing the sensor in the thigh was essential for monitoring the execution of certain exercises, but we are considering choosing an alternative exercise or placing the sensor in an alternative place. Making players feel uncomfortable with placing the wearable is not the experience we want the game to provide.

### 5.5 Competition Versus Collaboration

Despite our intention to promote collaboration within a team, we observed competitive behaviour of the seniors not only among, but also within the teams. We believe the reason behind the competitive behaviour was that mini-games had a linear progression from one side to the other, with players going in the same direction. This probably led seniors to conclude that they were on a race with each other, and thus engaged in competitive behaviour.

## 6 Discussion

This paper described a multi-player fall prevention game for seniors to use in senior care centres. The FallSensing games are one of few systems to: (i) focus on fall prevention, (ii) promote group exercises, and (iii) target senior care centres; and is the only one addressing the three characteristics simultaneously.

Using an exercising platform in senior care centres was very different from the home interaction context. For example, the role of the care worker was found to be determinant in the senior care centre, but such a role does not exist at home and studies do not talk about a supporting role when designing or evaluating systems for the home setting [17–19]. The issue with placing the sensors also seems to be characteristic of the senior care centre. The home has one or more intimate places (e.g., rooms), and the smaller distances between rooms would easily enable people to place sensors in their thighs away from guests. Moreover, the senior care centre is well suited for multiplayer games, while at home, seniors may live alone. The expectation that people would be alone at home probably influenced existing solutions to focus on individual playing settings [21].

Regarding the overall system acceptance and since the threshold previously defined in the literature for comparison of SUS global score is 80.3 [2], our system scored almost this threshold, which is a very positive outcome and reinforce the conclusion that the system is perceived as being easy-of-use and provides a global positive measure of system satisfaction.

Regarding the effect of interventions in terms of exercise monitoring, the majority of solutions in the literature used a variety of outcome measures and study designs, making it difficult to directly compare them with our solution [21]. Moreover, balance is clearly the main focus across the majority of the commercially available solutions, among a wide range of physical functions that could be simultaneous evaluated and targeted [21]. Our solution was designed not only to address balance retaining but also to promote mobility and muscular strength targeting more than one physical function simultaneously which constitutes the major advantage in respect to most commercially available exergames.

## 7 Conclusions and Future Work

This paper presented multi-player fall-prevention games for seniors, which are fun, easy-to-use, and well accepted among seniors in senior care centres. The role of the care worker was found to be preponderant during the game play, and competition revealed to be pervasive over collaboration. We believe fall-prevention games in senior care centres have potential to help preventing falls considering the usability and acceptance of the system during the trials.

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