Lessons Learned from Gamifying Functional Fitness Training Through Human-Centered Design Methods in Older Adults

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Abstract

Background: The design of meaningful and enjoyable Exergames for fitness training in older adults possesses critical challenges in matching user’s needs and motivators with game elements. These challenges are often due to the lack of knowledge of seniors’ game preferences and technology literacy as well as a poor involvement of the target population in the design process.

Objective: This research aims at describing a detailed and scrutinized use case of applying human-centered design methodologies in the gamification of fitness training routines and illustrates how to incorporate seniors’ feedback in the game design pipeline.

Materials and Methods: We focus on how to use the insights from human-centered inquiries to improve in-game elements, such as mechanics or esthetics, and how to iterate the game design process based on playtesting sessions in the field.

Results: We present a set of four Exergames created to train the critical functional fitness areas of older adults. We show how through rapid prototyping methods and multidisciplinary research, Exergames can be rigorously designed and developed to match individual physical capabilities. Moreover, we propose a set of guidelines for the design of context-aware Exergames based on the lessons learned.

Conclusion: We highlight the process followed; it depicts 19 weeks of various activities delivering particular and actionable items that can be used as a checklist for future games for health design projects.

Keywords: User-centered design, Motion tracking, Fitness training, Exergaming

Introduction

Physical activity is now recognized as a global public health priority and insufficient physical activity (PA) is the fourth leading cause of death worldwide. More than 30% of the world population is not meeting the minimum recommendations for PA, and 6%–10% of all deaths from noncommunicable diseases may be attributed to sedentarism. Information and Communication Technologies (ICT) show potential for improving behavioral change, with regard to PA, through global positioning systems, wearable devices, persuasive technologies, and interactive videogames. Combining game technologies, applied research and health care professionals allows the extension of the application domains of ICTs to topics such as training, health education, disease prevention, and aging. According to Deterding et al., gamification uses game elements to motivate and engage people in nongame contexts. In this regard, the so-called Exergames aim at promoting PA by enhancing the experience through gamifying elements that engage players through interactivity, game challenges, points, rewards, and entertainment. This engagement may enable longer-term adoption and better adherence to the training program than conventional methods. In fact, Exergames have been under investigation in recent years and show a high potential to promote PA in multiple environments and populations. Research has shown encouraging findings for
their role in motivation for exercising, improvements in cognitive function, and physiological energy expenditure. Interestingly, the use of Exergaming in the older population has shown likely positive impacts on physical and mental health. Physical, balance, and postural control benefits have been widely reported as critical areas where Exergaming practice has a clear positive impact. Other functional fitness domains, such as cardiorespiratory or muscle strength, have been less explored. Nevertheless, some studies reported significant increases in PA participation, overall functional fitness function (e.g., flexibility, strength, endurance) as measured by standardized tools, motivational aspects in older adults under multidimensional training programs delivered through Exergames. Regarding cognitive improvement, Exergames have shown positive results in selective attention, visuospatial skills, executive functions, and processing speed. Only one study reported cognitive benefits of multidimensional physical training with Exergames specifically in older adults; improvements in shifting attention, working memory, and long-term visual memory after a 6-month intervention were demonstrated. Other mental effects of Exergaming interventions have been observed, including differences across interventions in enjoyment, immersion, and flow, critical game user experience variables that reinforce the fun aspect of playing Exergames. Fundamentally, Exergaming aims at overcoming some of the previously identified common barriers for PA by (1) providing a real-time feedback of users’ performance; (2) allowing a more appealing and engaging way to carry out exercise while avoiding monotonous experiences; (3) recording the progress, providing measurable and quantifiable effects of working out; (4) remotely connecting health professionals with patients to facilitate supervised activities and promoting telerehabilitation programs, thus solving issues of transportation for older adults with limited mobility.

Still, several reviews in the field point out the need for additional research on the long-term adherence to Exergames specifically designed for the older population. A crucial aspect of ensuring both adherence to Exergames and their effectiveness in producing health benefits is a proper design process. Commercial Exergames are frequently used by researchers to explore multiple effects of Exergaming. Commercial Exergames are frequently used by researchers to explore multiple effects of Exergaming, but this repurposing approach raises concerns. The effectiveness of Exergames has been questioned due to the absence of experiments that compare the effects of Exergames against conventional approaches, lack of strictness in research protocols, and evidence of long-term adoption as well as limitations in the sample sizes of the experiments. Particularly, more research performed directly in the seniors’ natural context, performed with a more careful observation process and applied this model to the development of highly engaging Exergames for exercise promotion and fitness training. In this study, we used RCD to create an integrative model of our physically active older adults as the target population and applied this model to the development of highly engaging Exergames for exercise promotion and fitness training. Mainly, we used a specific RCD process called focused-RCD, which is intended to be carried out in 6 to 10 weeks with a sample of 8 to 12 users.
deliver sufficient and efficient PA, the training areas should include aerobic fitness (cardiorespiratory), musculoskeletal function, flexibility, and balance (or neuromotor). The features of the recommended exercise are normally described using the FITT (frequency, intensity, time, type) model. For instance, recommended activity intensity for the older population is moderate (5–6 in a 0–10 physical effort scale), with an accumulated time of 150 minutes per week.43 These guidelines apply to all adults 65+ years of age as well as to adults 50–64 years of age. It is worth mentioning that reviews of literature in the domain of Exergames for older adults highlighted the importance of including multiple physical functions in a structured way that follows health standards and well-defined protocols.14,52 Past investigations with a large group of older adults (n = 802) established a positive association between functional fitness and PA, allowing a preliminary identification of the dimensions that should be trained through Exergaming.44 Therefore, we aim at providing specific examples of the development process of Exergames for functional fitness training in older adults, and a set of guidelines that express the lessons learned along the process. Our ultimate goal is to create a set of Exergames that can meet the ACSM recommendations in the different fitness domains by offering a high level of training personalization with a fine-grained game parameterization.

Our approach

This article describes our effort to introduce a structured and systematic methodology for the design of Exergames targeted at Portuguese older adults. We designed and developed a set of Exergames, which combine standardized fitness training programs and a contextually rich user modeling process to overcome current limitations in the use of Exergames by older adults. We introduce a design framework that addresses critical aspects of the process, such as:

- Human-centered approaches in different stages of the game design process;
- Emphasis on fun experiences through playful interaction and gamification elements (story, aesthetics, mechanics, and technology);
- Integration of health professionals in the design process to identify health-related standards to be incorporated in the Exergames;
- Rapid prototyping and fast iteration with end users.

This study presents the whole design process from the definition of the health requirements to the final polishing stage of the proposed Exergames. Our experimental scenario is a senior gymnasium frequently used by active adults to exercise, socialize with their peers, and participate in several cultural activities. We aim at inquiring into methodologies for designing enjoyable and scientifically valid Exergames, which promote exercise in older adults, by adopting human-centered design processes. Specifically, we wanted to answer the following research question: how should human-centered design methods and insights be used to design highly contextualized Exergames for exercise promotion in older adults (aged 55+)? By answering this question, we will aid in the adoption of Exergaming technologies that might enhance the quality and quantity of PA, improve training personalization, and diversify working-out practices.45,46 Additionally, we wanted to know the feasibility of combining iterative game design with human-centered design methodologies in the design of a fitness training program based on Exergames for older adults.

The next section briefly describes the state of the art in the use of human-centered design approaches for Exergame design as well as existent guidelines for Exergaming design.

Related Work

Human-centered design and Exergames

Human-centered design has been used to inquire about the benefits of and barriers to older adults playing videogames,47 gaming preferences, personalities, and motivators,48,49 the design of user-oriented Exergames for fitness promotion,50 gamifying systems for children’s nutrition and fitness education,51 and entertainment.52 Research shows that older adults are widely different from younger cohorts in their game preferences in terms of playability, challenges, and motivators.21,53 Moreover, methods such as focus groups have highlighted the importance of perceived benefits, difficulty, and relevance for engaging with new technologies.54 Since the personalization of Exergames has been reported as one of the major bottlenecks in probing the effectiveness of this technology when applied to seniors,55 the use of participatory and inclusive design methodologies can facilitate technology adoption by them. Indeed, multiple researchers have identified the human-centered design approach as adequate and preferable in the design of compelling, useful and usable Exergames for exercise promotion.50,56 For instance, Uzor et al. demonstrated how empowering seniors with design tools and techniques could boost the likelihood of creating enjoyable rehabilitation tools for fall prevention.57 Participants have been modeled using Personas, facilitating the understanding and communication of their characteristics and needs.38,58 The fact that senior adults tend to show different levels of technological literacy and videogame experience must also be considered.59,60 This presents an exciting challenge and opportunity to develop novel assistive technology for the older population.61 Because the current Portuguese elder population has little to no experience with videogames, starting a design process by inquiring about preferred videogame mechanics, aesthetics, or technologies is not an adequate method. Multifaceted and participatory approaches have been widely recommended by physicians and sports scientists, stressing the need for clearly defining an appropriate fit-of-game design elements for each target group.60

Guidelines and frameworks for Exergame design

Exergaming research is growing fast, and results from several studies have defined valuable design guidelines. Table 1 shows five different sets of design guidelines for Exergames found in the literature, each created for specific goals and populations. The guidelines included in the table were chosen considering four criteria: (1) being Exergame design guidelines, as opposed to recommendations for development or validation, (2) their previous or potential use with older adults, (3) their origin in field studies instead of theoretical approaches, and (4) their clarity in defining...
<table>
<thead>
<tr>
<th>Name</th>
<th>Goal</th>
<th>Population</th>
<th>Guidelines</th>
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</table>
| **Designing for movement quality in Exergames.**<sup>52</sup> | Fall prevention exercises | Senior citizens | 1. Weight shift: Elicit weight shift in players by motivating them to move around a larger physical area and displace their center of mass.  
2. Temporal variation: Provide temporal variation in movements by offering adaptive changes in game speed.  
| **Guidelines for the design of movement-based games.**<sup>53</sup> | Entertainment | Overall | 1. Movement requires special feedback: “…instead of trying to remove this (the movement) ambiguity, work with it: players enjoy surfing uncertainty and trying to figure out optimal strategies in a somewhat messy system.”  
a. Embrace ambiguity  
b. Celebrate movement articulation  
c. Consider movement’s cognitive load  
d. Focus on the body  
2. Movement leads to bodily challenges: “…intend fatigue when using it as a game challenge but avoid it when it is not part of the game.”  
a. Intend fatigue  
b. Exploit risk  
c. Map imaginatively  
3. The movement emphasizes certain kinds of fun: “Movement becomes easier with a beat, so support players in identifying a rhythm to their movements.”  
a. Highlight rhythm  
b. Support self-expression |
| **A methodology for the design of effective and safe therapeutic Exergames.**<sup>54</sup> | Therapeutic (balance and posture, neglect rehabilitation) | Poststroke patients | 1. “A clear identification of all the exercise requirements, not only in terms of goals of the therapy but also in terms of additional constraints.”  
2. “…Discussion between clinical and ICT (Information and Communication Technologies) teams allows maximizing the effectiveness of Exergames implementation.”  
3. “The final Exergame is realized by introducing on top of the exercise all the game elements suggested by good game design to maximize entertainment.” |
| **Exergame design guidelines for elderly.**<sup>55</sup> | Enhance physical and social activities | Elderly | 1. Mind the physical condition: “…consider the physical condition of elderly, since age-related processes may have an impact on the ability to move.”  
2. Use appropriate gestures: “It should not be required that the players have to perform a gesture to trigger another action.”  
3. Avoid small objects.  
4. Give visual and auditory feedback. |
| **FitForAll approach**<sup>15</sup> | Exercise and maintenance/advancement of healthy physical status and wellbeing | Senior citizens | 1. Physical condition considerations. The range of motion, adaptability. Continuous player support.  
4. Adjustable difficulty. Exertion management. Record/display users’ past behavior  
5. Encourage social interaction.  
comprehensible items that could be easily transformed into actionable items.

These guidelines provide a useful starting point for the development of novel Exergames. Nevertheless, practical examples on how to incorporate users’ feedback in the design process, and on how to use the insights from human-centered inquiries to improve in-game elements, such as mechanics or esthetics, and provide valuable recommendations for such process are still scarce.

Procedure

Exergame design and development

We started the process by designing a set of Exergames based on the examination of health requirements. A complete process diagram can be seen in Figure 1, which depicts all the steps from the conceptualization until the polishing stage.

Exergame conceptualization. Requirements and input from experts

Two different sources of information were used for the health requirements analysis: (1) population characteristics (health screening) and (2) assessment of functional fitness status. We identified that the relevant components to be trained and measured through Exergaming were: motor ability (balance, agility, and flexibility), aerobic endurance, and muscular strength (lower and upper limbs and trunk). Additionally, we identified three levels of training profiles: low, moderate, and high functioning. These profiles allow for balancing the intensity of training to users’ fitness levels, also called the effectiveness loop in the dual flow model. For balancing the intensity of training to users’ fitness levels, also low, moderate, and high functioning. These profiles allow for balancing the intensity of training to users’ fitness levels, also called the effectiveness loop in the dual flow model.

The biggest challenge in the game design process was in the ideation of an Exergame universe that would embrace the specified health requirements. How can we design thoroughly fun Exergames starting from predefined fitness/exercise recommendations avoiding the chocolate-covered broccoli effect?

Technology selection. First, we gathered with three senior researchers of games for health to define an initial set of candidate technologies that would be adequate for a training program based on Exergaming. Motion tracking and physiological computing technologies were considered for the design of an integrated solution that could be used in both controlled (e.g., laboratory) and noncontrolled (e.g., senior gymnasiums) environments. The Kinect V2 (Microsoft, Redmond, WA) motion-tracking controller was chosen because of both its noninvasiveness as well as its low cost. Additionally, the Kinect V2 sensor allows an accuracy sufficient for the current application, tracking 25 joints distributed along the whole body for standing and sitting postures. In all the Exergames, we decided to use a floor-projection setup to facilitate the game mechanics and PA matching. One of the advantages of using floor-projection setups for videogame interaction is the possibility to use large physical surfaces, thus, avoiding spatial constraints.

The setup includes a PC, a projector, a white PVC (polyvinyl chloride) surface (2.5 m x 3.0 m), and the Kinect V2 sensor located ~ 3 m in front of the users (Fig. 2). To facilitate the interaction, we also explored the use of spatial augmented reality, which allows the augmentation of real-world objects and spaces using simple projections instead of special displays. With this technology, users can physically interact with the objects placed in virtual environments and projected on the floor in real scale.

Game ideation. For the Exergames ideation stage, we used brainstorming. We focused on the creation of multiple videogame stories enclosed in imagined virtual scenarios in which the users’ playful interactions would be concealed exercises. These scenarios would define a narrative and a universe for the Exergames. After ~ 10 short (20 minutes) brainstorming sessions, involving game designers and sports professionals, we came out with five categories of activities, each with multiple possible scenarios, as follows:

- Fantasy: space exploration, medieval live, maritime activities, and aviation.
- Sports: Olympic Games, traditional Portuguese games, and martial arts.
- Professional manual labor: agriculture, food preparation, animal care, mineral exploration, gardening, hospital activities, automotive mechanic, child-care, and construction work.
- World traveling: continental or national tourism.
- Creative oriented activities: painting, sculpting, dancing, and fashion design.

These ideas were combined with the predefined exercises for physical training and, ultimately, we decided to choose the world-traveling category to develop a virtual tour in Portugal. We based our choice on the hypothesis that through culture-specific elements, illiterate users would feel more identified and engaged with the Exergame experiences. Preliminary ideas involved developing Exergames that would feature iconic activities specific to Portuguese culture. The idea was then presented to and discussed with a fitness trainer in a local senior gymnasium, and the concept was refined by identifying exciting places and activities that could engage the aged audience (see Concept Presentation and Concept Refinement in Fig. 1). A game design and a specification document was produced detailing initial ideas for possible exercises taking place in the imagined virtual universe (as recommended by game design frameworks). Once the core of the story component was established, we engaged in the development of the game mechanics in a game jam.

Exergame development jam. After the conceptualization, we used a rapid iterative prototyping approach, which was implemented in a local game jam. The jam was carried out in a research laboratory facility and lasted about 40 hours along five consecutive days. The very first activity completed was a visit to the local senior gymnasium, where participants had the opportunity to observe conventional exercise sessions with a group of around 30 senior adults. Three videogame designers, three graphical artists, two psychologists, two sport science professionals, five
FIG. 1. The flowchart diagram of the design process describing people involved, inputs, deliverables, and design stages. The duration of the process was 19 weeks, divided into four main stages: conceptualization, initial development, rapid contextual design and iteration, and polishing.
programmers, and three games for health experts participated actively. The jam teams were divided and given different fitness domains to cover, following the health requirements described previously. We emphasized and prioritized the importance of making Exergames appealing, meaningful (regarding health and social benefits), and playable for older people with different preferences.12 Since this population is very heterogeneous, the development of a generic and poorly personalized experience will end up as a minimal solution for exercise promotion.14

Three different presentations of playable demos took place during the Exergame jam for evaluation of the prototypes. Two health professionals from a senior gymnasium and three games for health experts evaluated the videogames in different stages. At the end of the development jam, the first version of the Exergame prototypes had a high percentage of the game story completed while a moderate percentage of the game mechanics and a low percentage of the game esthetics were completed. At this stage, we had a set of virtual experiences covering four different places in Portugal that addressed all fitness domains. Prototypes were further developed (see Exergame’s prototype development in Fig. 1) and iterated until they were robust enough to carry out a field test in a local senior gymnasium in Madeira, Portugal.

An Exergaming experience through Portuguese traditions. At the end of the 1-week jam, our vision to create a virtual tour in Portugal materialized in a set of Exergames covering several touristic activities in different places (Fig. 3 and Table 2).

Applying human-centered design methods for inquiring about Exergaming preferences: hands-on with the RCD process

After the game jam, the next efforts were centered in testing the second version of the prototypes with end users and in the collection of structured feedback. Following the focused RCD process, we designed three different surveys: a

FIG. 2. Setup for the Exergames consisting of a Kinect V2 sensor and a virtual environment projected on a floor surface. PVC, polyvinyl chloride.

FIG. 3. Screenshots of the initial prototype Exergames. (A) Grape stomping, (B) Rabelos, (C) Exerfado, and (D) Toboggan Ride.
Table 2. Description of Each Individual Exergame, Portuguese Tradition, Goal, Fitness Domains Addressed, and Related Movements

<table>
<thead>
<tr>
<th>Exergame (Portuguese Region) description</th>
<th>Goal and score</th>
<th>Fitness domain and movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grape Stomping (Douro Region): wine making through crushing grapes barefoot to release the juice.</td>
<td>Goal: Grape maceration to produce wine by stepping on virtual grapes placed into open tanks.</td>
<td>Cardiorespiratory training: Flexion-extension arm movements are needed to drag the grapes into the tanks. Then, the stomping process starts, requiring users to repeatedly raise the knees. After filling up one tank, users can move to the others to continue the exercise. Score: liters of wine produced.</td>
</tr>
<tr>
<td>Rabelos (Porto City): wine barrel transport in cargo boats navigating in the Douro river.</td>
<td>Goal: Transport barrels of wine along the Douro river by rowing in a boat avoiding rocks and collecting more barrels in the riverbanks.</td>
<td>Upper limb muscular strength: Perform circular arm movements simulating rowing gestures to move the boat forward. For lateral displacements of the boat, standing users can use either lateral movements or trunk leaning; or they can be seated and use trunk leaning only. To navigate the rapids, users must avoid rocks by rapid lateral movements. To pick up the barrels, users must turn the trunk to the dock and make an extension/flexion movement of the elbow. Score: Quantity of barrels collected.</td>
</tr>
<tr>
<td>Exerfado (Lisbon City): Fado music playing by a melodic guitar soundtrack.</td>
<td>Goal: Catch the correct notes by selecting of the frets in a virtual guitar (GuitarHero-like game).</td>
<td>Lower limb, flexibility: Players collect notes by performing rapid lateral movements to select the correct guitar’s fret. Players should move their entire body to collect the musical notes since the paddle reflects the movement of the hip. Once empty, the music score can be refilled using a “turn the page” or swipe gesture with the left hand extended. Score: Number of successfully collected musical notes.</td>
</tr>
<tr>
<td>Toboggan Ride (Madeira Island): a downhill journey in a sledge sliding car.</td>
<td>Goal: Control the direction and acceleration of the car to collect items placed on the street</td>
<td>Balance, trunk muscular strength: The sledge direction is controlled through trunk lateral flexions while the acceleration is controlled through trunk flexion/hyperextension movements. Flexion movements are used to increase the acceleration of the vehicle while hyperextensions are used to deaccelerate it. Score: Number of successfully collected banana bunches.</td>
</tr>
</tbody>
</table>

Table 3. Characteristics of the Participants

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age</th>
<th>Schooling (years)</th>
<th>Previous or current occupation</th>
<th>Time in the gym (years)</th>
<th>Hours of physical activity (weekly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>56</td>
<td>12</td>
<td>Accountant</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>57</td>
<td>9</td>
<td>Homemaker</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>56</td>
<td>12</td>
<td>Homemaker</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>67</td>
<td>0</td>
<td>Homemaker</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>70</td>
<td>0</td>
<td>Homemaker</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>57</td>
<td>9</td>
<td>Factory worker</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>67</td>
<td>4</td>
<td>Telephone operator</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>59</td>
<td>4</td>
<td>Cleaning services</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>72</td>
<td>9</td>
<td>Retired</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

F, female; M, male.
demographics form, a videogame experience questionnaire, and a final survey from which we collected feedback related to the Exergaming experience.

Demographics. Participants for this study were selected from the older adults population exercising (at least 2 hours/week) in the senior gymnasium. Participants were invited by the gym trainers to collaborate in a structured interview, which included interaction with a gaming system under development that would potentially be used to complement their exercise routines. Volunteers included nine (9) older adults (8 females, \( M = 62.3, SD = 6.2; 1 \) male) (Table 3). Participants signed an informed consent before participation.

We used a modified version of the Baecke questionnaire\(^7\) to query users about their levels of PA. The Baecke questionnaire is a tool that assesses qualitative and quantitative indices of dimensions such as weekly physical exercise practice and leisure-time activities during the last 12 months. The hours-per-week estimate for the different activities is multiplied by the respective metabolic rates (expressed as metabolic equivalent [METs]) to obtain the energy expenditure during both sports practice and active leisure time. From that, we computed the Sport Index—which is a global measure of exercise practice embracing frequency and intensity—and the Leisure Time Index. Both indexes are descriptive of the activity level of the participants and are expressed in MET values (Table 4).

Contextual inquiry. Since attitudes, behaviors, and personal opinions are usually challenging to capture, observation and shadowing of users\(^7\) during the work-out time was performed on different days of the 2 weeks preceding the data collection process. We conducted informal conversations with end users to aid the identification of relevant contextual information; data were used to complement the user modeling process.

The videogame experience questionnaire (Supplementary Appendix SB) was used to investigate two main topics:

- Patterns of digital gameplay: frequency, intensity, history, social aspects, and perceived skillfulness of gameplay.
- Motivators to play: how they started to play, favorite games and videogames, attractive elements for videogames, interest to start/continue playing.

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sport Index (min 1–max 4)</td>
<td>3.3</td>
<td>3.0</td>
<td>3.3</td>
<td>2.3</td>
<td>2.8</td>
<td>3.0</td>
<td>3.3</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Leisure Time Index (min 1–max 4)</td>
<td>2.9</td>
<td>2.9</td>
<td>2.7</td>
<td>2.6</td>
<td>3.1</td>
<td>2.3</td>
<td>3.1</td>
<td>3.4</td>
<td>2.7</td>
</tr>
</tbody>
</table>

FIG. 4. Image representing the model from the realistic senior Skeptic Persona.
The interviews were semistructured questionnaires with one interviewer and one note-taker present. A predetermined set of questions were asked and the inquiries tailored with follow-up questions based on each interviewee’s answers. This strategy was made to encourage interviewees to expand on their initial comments. Data were collected in individual sessions lasting around 1 hour per participant in a designated room at the senior gymnasium, where the system was set up. After a complete explanation of the procedure, participants signed the consent form and the demographic information was collected. Posteriorly, the videogame experience questionnaire was used to collect game literacy information. The system setup and Exergame prototypes were introduced to participants who had the opportunity to interact individually with them and provide feedback right after each playtest.

Contextual interview interpretation and users’ Personas. Following the focused RCD methodology, we conducted:

- **Contextual interview interpretation**: we analyzed the exercise routines of the older adults in the gymnasium, their socialization, and relationship with colleagues and fitness instructors. We were focused on identifying intrinsic motivators, main barriers, and possible facilitators for exergaming for our local population in their gymnasium.

- **Work modeling**: we focused on the development of multiple sequence models of daily exercise practice in the gymnasium, which represent the ordered steps in which a senior performs the prescribed activities. Subsequently, we designed possible scenarios of interaction with the Exergames inside the gymnasium and represented them as sequence models of activities. This helped us to envision future user experience issues and contrast them with the information collected from the real interaction using the digital prototypes (Modifications to the Exergames section).

- **Affinity diagram**: during the observation and shadowing processes, detailed field notes were taken, coded, and subsequently merged with the notes from the contextual inquiry and Exergaming experience. Since we were interested in viewing the opportunities to integrate Exergaming practices in the senior gymnasium, an affinity diagram was used as a starting point for constructing design considerations. We coded the information based on users’ preferences toward doing exercise at the gymnasium and behaviors that might reflect barriers to integrate the Exergames in their daily life activities. Also, we clustered some definitions used by participants to describe their notions about videogames. Finally, the diagram revealed information regarding the users’ habits and behaviors during exercise practice in the gymnasium as well as connections between technical elements and

![FIG. 5. Image representing the model from the realistic senior Curious Persona.](Image)
the users’ perception of videogames. The affinity dia-
gram was used to (1) categorize older adults, bearing in
mind their opinions and experiences with technology
and (2) compile a list of insights and design ideas to
modify the Exergames considering the feedback gath-
ered from the users and instructors.

• **User Personas:** users’ archetypes for the active senior
  population were modeled according to the treated in-
  formation. We focused on their willingness to integrate
  videogames into their lives. We identified two main
types of information to create our users’ Personas.
  o Personal habits and PA practice: information related
to the activities during the leisure time, ways of
  exercising, preferences regarding activities of daily
  life and barriers.
  o Technology literacy and game experience: information
    regarding past experiences with gaming devices such
    as videogame consoles, PCs, and mobile devices were
    considered to create a technological curriculum for the
    seniors. We focused on the motivators for playing
    Exergames such as social elements,75 health issues,
    and curiosity levels.

The models for the user’s Personas contained the follow-
ing information:

- **Basic information:** a picture of the processed arche-
type, a small quote reflecting a personal opinion about
  videogames, hobbies, and preferred activities (such as
  traveling, exercising, and having fun with children).
- **Personal information:** a short biography describing
  some characteristics of the user’s personality, such as
  preferences and habits, together with the PA agenda
  and representative goals and frustrations.
- **Technology literacy and gaming willingness:** tech-
  nology literacy is primarily expressed in terms of past
  experiences with computers, mobile phones, tablets,
  and videogame consoles. Six bar scores denote spe-

**FIG. 6.** Image representing the model from the idealistic senior Enthusiastic Persona.

**FIG. 7.** Playtesting scenario depicting a user playing Grape Stomping.
specific motivations to play Exergames: fun and pleasure, escape from daily routine, social interaction, physical health, mental health, and curiosity about new experiences.

Two realistic and one ideal user Personas were modeled. The realistic models are a Skeptic and a Curious archetype (Figs. 4 and 5), referring to the senior’s willingness to use videogames in their daily routines. A profound mistrust over the possible health and social benefits of using videogames characterizes the skeptic persona. This view is firmly based on the limited past experiences some older adults have with gaming technologies, which is reflected as a simplistic vision of playing videogames: a waste of time. More than half of the interviewed users were identified as Skeptic users.

The Curious Persona is not indifferent to the incorporation of technology into her daily life activities. She has had some previous experiences with videogames and it had a positive impact on the perception of how useful videogames can be concerning social interaction and fun. Curious users are more prone to accept the use of Exergames for exercising.

Finally, the ideal user is the Enthusiastic. Although in this research we did not find active senior gamers, we wanted to model the ideal user to understand the conditions for the long-term adoption of Exergaming. The Enthusiastic archetype has a medium-high ability to interact with computer, mobile devices, or videogame consoles. This user uses videogames in her daily life routines, strongly believing in their health and social benefits (Fig. 6).

The consolidated models and the revealed affinities were evocative representations of the interviewed older adults, covering an amalgam of elements such as fitness habits and characterization, social behaviors in the gymnasium, personal perception about the use of technology for exercise, and characteristics of senior needs in terms of engagement and motivation to make exercise routines.

**Iterations and feedback**

**Playtesting with the target population.** With the second version of the prototypes of the Exergames, we conducted a first playtest with the target population at the senior gymnasium with the same users that participated in the contextual inquiry (see *Gym Playtesting* in Fig. 1). The interaction with each Exergame took about 5 minutes and then users were asked to enumerate: (1) three videogame elements they liked, (2) three videogame elements they did not like, and (3) three things they would like to add/remove from each Exergame. Finally, we asked their opinion on how to integrate the Exergames in the gymnasium. Videos from the experience were recorded to be analyzed afterward (see *Feedback Data* in Fig. 1). Participants’ interactions with the Exergames were recorded to be analyzed by the principal investigators and game programmers to identify problems with the game mechanics, particularly the gesture interaction. Figure 7 shows the playtesting scenario with the technical setup.

We also carried out informal interviews with two exercise instructors from the gymnasium to understand their needs and reactions to the Exergames. They supported the Exergames’ mechanics, the story theme, and provided specific requirements such as:

- Include strategies to teach movements gradually, one at the time: for instance, while interacting with the Rabelos Exergame, one of the users claimed to have “difficulties in coordinating the movements and understanding the movements” suggesting the need of more explicit feedback for learning.
- Increase the challenge to enhance workout effects: for instance, while interacting with the Exerfado Exergame, one of the users stated wishing for “more rhythmic music” to get a more dynamic gameplay experience. Additionally, while playing the Toboggan Ride Exergame, one of the users claimed to need “more obstacles,” to increase the game difficulty.
- Allow broader customization of the videogame parameters to facilitate difficulty adjustment and the inclusion of seniors with movement limitations: for instance, while interacting with the Grape Stomping Exergame, one of the users claimed that in the game “it should be easier to push grapes since the movement can be bad for the shoulder,” illustrating how game difficulty perception may vary between subjects.

After gathering the feedback from the users and instructors, we carried out multiple development iterations on the prototypes aiming at improving the mechanics and -aesthetics as well as the usability of the system (see Exergames Mechanics, Esthetics, and Usability Revision in Fig. 1). A list of improvements was merged with the users’ Personas models and the insights from the RCD process to generate the third generation of the Exergames. Final polishing tasks were done in the research laboratory before releasing the final version of the Exergames after 19 weeks.

Merging the information from both RCD and Exergaming feedback, we observed:

- **Social aspect:** older adults enjoy playing mainly for two reasons, they like to win competitions, and they find it to be an opportunity to socialize (skills and experiences). Multiplayer playability is a crucial factor to improve technology adoption.
- **In-time feedback:** for both the skeptic and curious profiles, the lack of past experiences with gaming technologies hinders a fluid interaction in different stages. It is imperative to have high quality and frequent feedback in the videogame to facilitate the understanding of what to do, how to do it, and when.
- **Customization of movements:** options for personalization must include clear strategies to facilitate the interaction for people with diverse motor abilities. Since each Exergame includes a set of various body movements (e.g., drag and step, row and navigate), health professionals should be able to activate/deactivate individual body gestures depending on users’ abilities.
- **Cognitive tasks:** the inclusion of more cognitively demanding activities in conjunction with physical exertion might enhance health benefits and increase engagement, and consequently the likelihood of long-term adoption of this technology.
Parameterization: the multiple game parameters facilitate the personalization of activities regarding fitness domains and training dimensions. By defining a set of game parameters, the difficulty will be controllable, allowing a more precise adaptation to the specific motor and cognitive skills.

Modifications to the Exergames. Several changes were made in each Exergame, which aimed to incorporate both the RCD insights and Personas as well as the feedback data obtained from the playtests. The most relevant changes are the addition of multiplayer options, instructional videos for in-time feedback, and the parameterization of each game. Table 5 summarizes the changes made in each game after the iteration process.

After this iteration process, the graphical elements of each Exergame were improved. The GUI (Guide User Interface) was made uniform across all the menus, including the in-time feedback for gesture guidance and a panel for text and video instructions. We included English and Portuguese languages for the initial configuration menu, a tutorial, in-

<table>
<thead>
<tr>
<th>Exergame</th>
<th>First implementation</th>
<th>Implementation after iterations</th>
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<tr>
<td>Grape Stomping</td>
<td>(a) Single player. (b) No instructions supplied. (c) Pull and step. (d) Only physical challenge. (e) Nonparameterized winemaking process.</td>
<td>(a) Single and multiplayer (collaborative or competitive). Users are situated in different tanks. (b) A tutorial providing in-time videos for feedback in the drag, stepping and lateral movements. (c) Pull and/or step. (d) Physical and cognitive challenges. Cognitive challenges were added using wine recipes. (e) The treadmill velocity and the number of steps for winemaking parameters were added for difficulty modulation.</td>
</tr>
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</table>

| Rabelos      | (a) Single player. (b) Instructions used images and were displayed at the beginning. (c) Rowing and boat lateral displacement. (d) Nonparametrized course. (e) Predefined calibration for the floor. | (a) Single and multiplayer (collaborative or competitive). Users embody different boats. (b) A tutorial providing in-time video feedback for the rowing, lateral displacements and barrels pick up gestures. (c) Optional rowing and/or boat direction. Either can be automated by the system. (d) Docks and rocks separation distance was added as game parameters for difficulty modulation. (e) A calibration module was added to the project allowing an initial configuration of the spatial parameters for the position tracking. |

| Exerfado     | (a) Single joint interaction. (b) Only one song was used. (c) Nonparametrized gestures and song-tracks. (d) No clear audiovisual feedback supplied. | (a) Waist and feet tracking. (b) MIDI files can be added. (c) Four parameters addressing arm extension, the time between notes, note sliding time and song track can be used to personalize the experience. (d) A swipe gesture visual feedback was added in conjunction with audio feedback for punishment and reward. |

| Toboggan Ride | (a) Single player. (b) No instructions supplied. (c) Direction control only with trunk lateral flexions. (d) Nonparameterized course. Only objects to collect. (e) Predefined calibration for the floor. (f) Male avatar. | (a) Single and multiplayer (collaborative or competitive). Users placed in different toboggans. (b) A tutorial providing in-time videos for feedback on the car’s acceleration and deceleration as well as for the car’s direction. (c) Lateral displacements were added to control the direction of the car. (d) We added elements to avoid in the scene and a control parameter for the distance between the objects to collect. (e) A calibration module was added allowing an initial configuration of the spatial parameters for the position tracking. (f) Male and female avatars. |

MIDI, Musical Instrument Digital Interface.
time instructions (they appear sequentially to support users along the experience), and a final screen with the game metrics. Figure 8 shows screenshots of the final version of each Exergame.

Finally, Table 6 summarizes the Exergame parameters that can be set to adjust the difficulty of the fitness training dimensions. The table shows how specific sets of game parameters cover all fitness domains.

Guidelines for Context-Aware Exergame Design

Past paradigms for the development of fully engaging videogames, aimed at exercise promotion and rehabilitation, failed to provide clear elements for sustainable motivation.55 They failed at both system personalization6 and contextual information integration,76 thus limiting the impact of Exergames. Our study emphasizes the need for a paradigm shift that, through the combination of multiple HCI techniques, will generate Exergames for older adult populations that are more engaging and usable.

After analyzing our main results in designing Exergames through human-centered design and iterative approaches, we propose a set of guidelines that intend to summarize our efforts in constructing a methodology for Exergame design and development for exercise promotion in older adults.

a. Focus on human-centered approaches
   - Use agile software development and standardized methodologies (e.g., RCD).
   - Create user models to aid the communication process (e.g., Personas).
   - Go for the short and frequent field inquiries instead of a long and single interview.
   - Investigate the target population game preferences and interaction limitations to enrich the game design process frequently.

b. Increase emphasis on fun experiences through gamification elements
   - Balance attractiveness and effectiveness by intertwining storytelling with game mechanics.77
   - Exploit the familiarity of contextualized activities and factors (e.g., the wine industry in Portugal).
   - Consider elaborating a game design and specification document before starting the development process.

c. Improve collaboration with sports and health care professionals
   - Include professionals actively in each project stage.
   - Ask health care professionals to summarize and list the health requirements for the gamified system.
   - Promote spaces and situations that boost interactions between technologists and sports and health care professionals (e.g., game jams).
   - Include strategies to integrate technology in sports facilities and health care institutions beyond the research phase.

FIG. 8. Screenshots of the final Exergames. (A) Grape Stomping, (B) Rabelos, (C) Exerfado, and (D) Toboggan Ride.
d. Rapid digital prototyping and fast iteration

- Investigate existing software and methodological tools to accelerate the prototyping process before starting a development process from scratch.
- Include multiple playtesting sessions to evaluate game design elements with end users before the research trials.
- Contemplate at least three generations of prototypes in the project timeline.

**Discussion**

Transversal inquiries that consult users about technology preferences and systems' usability issues are not enough to effectively model senior’s personalities. Research-centered approaches conventionally start from an extensive scientifically-grounded review of the evidence, moving to system development, and finishing with a strict evaluation process with end users. On the contrary, an immersion into daily routines and preferences of end users is usually the first step in a human-centered intervention (also known as empathizing). User models of behaviors, preferences, habits, and needs may help revealing issues such as intrinsic (vs. extrinsic) motivations in using games as exercise, as well as conditions, preferred time, and intensities. Due to the wide heterogeneity of the elderly population, the design of highly personalized Exergames for exercise promotion or rehabilitation must include rich contextual information obtained directly from real-life scenarios. Balancing research-centered approaches with human-centered methods might enhance the design of the interventions. The development of three different user Personas from our study confirms the need to increase the personalization of the content, targeting a broader set of alternatives, which can satisfy specific user’s needs regarding personal preferences and health requirements. Since studies reflecting attitudes toward Exergaming technologies’ adoption and gaming affinities in our targeted population (Portuguese older adults) are scarce, we decided to create our own models to cover very specific aspects, such as willingness to play Exergames in the gymnasium, personal predispositions with gaming technologies, and motivators beyond pure enjoyment and/or novelty of the Exergames.

Moreover, dynamic modifications of videogame mechanics and aesthetics based on playtesting insights with final users might increase the familiarity with the storyline, facilitating the recognition of specific videogame elements (such as places and activities), which can elucidate memories of personal experiences or transport users to dreamed situations. Therefore, favoring user experiences for the elderly and increasing the possibility of long-term technology adoption. Concerning the adoption aspect, we ensured that all the Exergames developed had flexibility regarding game parameterization, thus reinforcing the possibility to create a more personalized game experience.

The convergence of both components from the dual flow model, effectiveness, and attractiveness, seems to be a dependable method for avoiding the development of Exergames with high health demands and inferior engagement levels. Attractiveness has been demonstrated to be a bottleneck factor in the popularization of Exergames among several populations. The gamification of specific exercise activities demands strategies to overcome stuck points in the design and development.
process. Following some of the guidelines presented in Table 1 for Exergame design,82,83 our efforts to gamify touristic activities and recreate Portuguese spaces include:

- Embracing the variability related to movements established in the health requirements, making them a part of the story instead of disconnected and isolated actions.
- Showing real-time feedback on movement quality to help senior users learn about movements and coordination.
- Designing the Exergames as virtual visits to different Portuguese regions to facilitate the generation of an imaginary journey, aimed at avoiding the classic static scenes for PA experiences. Also, the Exergames were designed under a narrative umbrella, which has the potential to enhance motivation and increase engagement77 during gameplay.
- Enriching the videogame experience through multimodal stimulation using thematic soundtracks for some Exergames as well as using the music itself as a videogame mechanic (Exerfado). Furthermore, the spatial augmented reality used in the Grape Stomping Exergame promises to become an exciting mediator between natural movements and the videogame rules and goals. Past research with this technology shows how promising it is in assistive technologies for rehabilitation purposes.67,84

The conceptualization of the videogame design stage as a collaborative and interdisciplinary process is required to guarantee balance between engagement and videogame effectiveness. We decided to use a robust theoretical basis in exercise prescription for our target population, the ACSM guidelines, which are the most widely used exercise guidelines for fitness training.32 Theoretical notions such as defining exercise training in terms of specialized fitness domains, such as cardiorespiratory and muscular strength, as well as predefining exercise intensities and movements allowed us to better define the gamification strategies from the beginning. Furthermore, these exercise guidelines were an important common point between game designers, researchers, and the sport science professionals, facilitating the communication and workflow in general. Although current approaches in games for health development are mainly driven by the research community,85 we believe that a closer relationship between sports and health professionals working in the field and experienced videogame designers/developers might make the difference for technology adoption. This intersectoral collaboration with health stakeholders should take place in a continuous timeline, transversally to the inquiry, design, and development processes.51,86 Videogame designers must be sure to fully understand the health requirements to provide benefits through a playful digital experience. On the other side, health professionals must be aware of technological constraints to gamifying training or health-related activities. This reciprocal knowledge provides a very rich scenario to balance both components in the dual flow model.62 Ironically, after research trials, many videogames developed do not become available, thus impeding their integration into health care units. Nevertheless, new web-based platforms have been promoting the sharing of novel serious games developed for health purposes, helping in more widespread use and adoption of these interactive technologies (https://neurorehabilitation.m-iti.org/openrehab, http://healthcaregames.wisc.edu, https://seriousgames-portal.org, http://serious.gameclassification.com). Considering physicians’, therapists’, and sport professionals’ levels of skepticism regarding the use of videogames for wellbeing purposes,87 a collaborative approach might help the adoption of these technologies in their daily work routines.

The fast pace of technology development has created tensions in serious gaming research due to the risk that the hardware/software used in the videogame will become outdated before its evaluation.88 Typically, health care interventions using serious games are developed after strict processes of literature review, protocol assessment, and short pilot studies with a small number of users and experts. Although Exergame design requires developers to be familiar with motion-tracking sensors and game engines, novel software and hardware tools have been developed to accelerate the creation of playable digital prototypes which can be used for initial tests.89,90 Then, as described in,91 health care interventions using ICT can utilize approaches focused on the evaluation of specific working mechanisms (such as videogame mechanics) rather than the operability of the complete system. Videogame playtesting can be used to iterate over concrete elements, which will strongly affect the user experience. Agile software development methods such as Scrum can be applied to game development.92 In this study, the videogames are continuously tested with final users providing valuable feedback that will drive the next steps in the development. This iterative process requires active collaboration between health professionals, videogame designers, and developers, and final users. For the development of our Exergames, we focused on testing several videogame mechanics, which was useful to find a good match between the required movements, the story proposed, and the affordable gestures for the Kinect sensor. Moreover, the Exergame jam provided an optimal scenario to exchange ideas between the different actors and foster cohesiveness between the teams. Interestingly, past investigations have shown how game jam events are viable approaches to rapid videogame prototyping as well as to generate interest in health-related issues.93 Finally, we highlight as strengths of our research approach: (1) the active participation of final users during design stages, (2) game design decisions based on real insights and data from the field, (3) the use of an iterative refinement process which avoids the chocolate-covered broccoli effect, and (4) “tunable” game parameters to improve training’s personalization.

Limitations

Despite the already-mentioned strengths of the research carried out, it is evident that due to the several challenges faced and the dimension of our highly multidisciplinary approach, several limitations can be identified: (1) time-demanding procedure, (2) input from several sources (e.g., researchers, designers, health professionals) can be challenging to manage, (3) the lack of a consistent, conclusive, fully reproducible, and straightforward method for contextually rich Exergame design, (4) the absence of clear theoretical frameworks for adopting human-centered Exergame design, and (5) a gender bias in our sample which might have impacted on the design decisions made. The gender bias arises from the fact that the clients of
the seniors’ gymnasiums, where we conducted the study, are predominantly females, which resulted in a heterogeneous sample in terms of gender.

Conclusion

Digital gameplay by means of Exergaming has the potential to enhance the motivation for doing PA by providing enjoyment and fun, and by stimulating physical and cognitive capacities. Traditional Exergame design processes often fail in systematically including end users’ gameplay preferences and main motivators, thus reducing their likelihood of being adopted and extensively used. In addition, practical examples of how to integrate end users’ feedback and contextual factors to enhance gamification strategies for Exergaming are scarce. In this study, we demonstrated that the usage of human-centered design methods for creating contextually rich Exergames allows a better understanding of underlying motivations and preferences for playing Exergames in older adults. Specifically, we illustrated how these methods and the produced insights were rigorously used in the Exergame design process, thus answering our main research question: how should human-centered design methods and insights be used to design highly contextualized Exergames for exercise promotion in older adults? First, we showed that together with health professionals’ feedback, rapid game development responses and a systematic iteration process, the contextual information could be effectively used to create more personalized and highly enjoyable Exergames. Second, we demonstrated how specific insights such as preferred social aspects, feedback modalities, cognitively demanding mechanics, and system’s customization features could be successfully integrated into the arduous task of generating pleasurable and gamified exercise experiences. Finally, Figure 1 shows very specific examples of which techniques were used in each stage of the design process, allowing the identification of inputs, processes, and deliverables. For instance, from the conceptualization stage, the game design specification document was key to facilitating the communication with the game developers. Furthermore, from iterations with playable prototypes in end users, a significant amount of feedback data was collected and processed to allow the identification of improvements in the game elements. After almost 20 weeks, we passed through many stages using several methodologies, which channeled our desire to bring a realistic and complementary view of how to gamify fitness training beyond points, leaderboards, and badges. Contextual factors should be continuously inquired to move toward a harmonious balance between effectiveness and attractiveness. We demonstrated the feasibility of combining methodologies from game design and human-centered design to produce a complete set of Exergames to support fitness training in seniors. To conclude, we believe that due to its diverse nature and flexibility regarding game parameters, this set of Exergames should be further developed and evaluated to enhance the motivation for doing PA by providing enjoyable and engaging experiences. Moreover, we would like to explore possible relations between the user personas found in our research with distinct player types (e.g., achievers, explorers, socializers, killers). Finally, since the Exergames are fully parameterized, and the structural foundations of its design are standardized fitness assessment tools for older adults, we believe they can be used with vulnerable populations, such as Parkinson or stroke survivors. Thus, we will carry out pilot studies to investigate the role of these contextualized Exergames beyond exercise promotion.

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Author Disclosure Statement

No competing financial interests exist.

Supplementary Material

Supplementary Appendix SA
Supplementary Appendix SB

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