

Design and evaluation of an exergame for motor-cognitive training and fall prevention in older adults

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ABSTRACT

Exergames have emerged as a strategy to promote physical activity and cognitive tasks through entertainment, being a promising solution for multicomponent training and fall prevention in older adults. Even though seniors may enjoy playing, game design is often not suited to this age group, which hinders interaction and user experience. Therefore, we developed a motion-based interactive game for motor-cognitive training in older adults, based on typical exergames, dance and Tai Chi. New forms of interaction based on inertial sensors and movement were included and tested with eight older adults in multiple sessions, during which usability and user experience were evaluated. People found the exergame fun, even though some challenges related to interaction were reported. Despite the challenges, people learned how to use the system and interaction has gradually become easier. In-game strategies to support interaction are required to encourage autonomous use devoid of supervision.

CCS CONCEPTS

• **Software and its engineering** → **Interactive games**; • **Human-centered computing** → **Human computer interaction (HCI)**; **Usability testing**;

KEYWORDS

Exergame, Motor-cognitive training, Fall Prevention, Elderly, Interaction, Usability, User Experience

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1 INTRODUCTION

Population ageing is one of the greatest triumphs of humanity, but it is, at the same time, one of the greatest challenges. One out of three community-dwelling adults over the age of 65 falls each year, and 20-30% of falls result in injury and hospitalization [38]. Besides the physical injury, falls can lead to fear of falling and restriction of movement, which may result in social isolation, depression and cognitive decline [34].

Fall risk increases as individuals age, due to changes on physical, sensory and cognitive domains [28]. Many of these changes are reversible and can be prevented, decreasing the chances of developing functional impairments and, thus, decreasing the likelihood of falling and injury [9, 28, 33]. Interventions targeting cognitive (i.e., attention and executive functions [10, 23, 37]) or motor functions (i.e., balance and strength [28, 31]) are able to enhance gait and reduce the risk of falling [30, 37]. The simultaneous training of both functions can result in greater benefits for the person [2, 4], yet adherence to clinical interventions is often very limited [14].

Exergames combine entertainment with physical activity and cognitively-challenging tasks. When properly designed, they promote engagement, behavior change and adherence to exercise [16], being also connected to positive mood changes, improvement of socialization and overall quality of life [16, 35]. The more physical and cognitive functions are targeted by the game, the more complex its design becomes. Even though seniors may enjoy playing, game design is often not suited to this age group, which hinders independent use and the successful implementation of interventions [1, 7, 24].

In view of the above, we developed an interactive video game for motor-cognitive training in older adults. The game is based on typical exergames, dance and Tai Chi, and uses four wearable sensors placed on both arms and legs to support motion capturing and evaluation. The diversity of the tasks and exercises included inspired a new game design with new forms of interaction supported by movement. The aim of the study was thus to assess interaction and usability, considering all the complexity associated to task diversity in multicomponent training. The solution was tested by eight independent older adults, who participated in three consecutive sessions. Our work drew on observation, questionnaires and semistructured interviews, and the analysis focused on usability and user experience.

After presenting some related work, this paper describes our solution, emphasizing game design and interaction. Methods and test sessions are then described, followed by a summary of results and opportunities for future work.

2 RELATED WORK

Research on exergames has dramatically increased in the last decade. Game consoles such as Sony Playstation¹, Microsoft Xbox² or Nintendo³ Wii³ were designed for entertainment and recreation, being nowadays very popular among the young population [16, 32]. As technology continues to be more accessible and affordable, it seems natural that it is used for more serious purposes, like stimulating physical activity and preventing falls in the old age.

Many studies have tried to use commercial games to target a wide variety of physical functions, including balance and strength in older adults [32]. Games, such as Wii Sports, Wii Fit, Eye Toy or Dance Dance Revolution, have been tested with seniors in short-term trials. While some studies reported significant improvements in balance [8, 27], strength [15, 18], gait [19, 25, 29] and cognition [21, 29], others could not find any effects [3, 15] or the effects were lower when compared to traditional physical therapy training [5]. Thus, there is still little evidence to support that commercial exergames are effective in preventing falls in the old age [32].

Participants have consistently reported exergame-based training to be highly motivating, with an improved sense of general wellbeing [16, 32]. However, the security of an independent practice devoid of supervision has been questioned [26]. Even though seniors may find commercial exergames fun and socially engaging, several interaction barriers were also identified, especially due to the speed and complexity of what was displayed on the screen [1, 20, 32].

On this basis, several custom-designed games for older adults were proposed ([11, 12, 22]). These exergames tend to be characterized by fairly simple designs and exercises, but still specific training is needed before seniors can use them independently [32]. Even though they address several issues related to interaction, the majority of the solutions target just one physical function, being rather difficult to establish the extent to which exergames can contribute to keeping older adults active and healthy [13, 32].

3 EXERGAME DESCRIPTION

To meet the challenge of improving interaction and usability of multicomponent exergames for older adults, while encouraging independent use, we developed new forms of interaction based on inertial sensors and movement. Motor-cognitive training was attained with captivating and challenging exergames, that incorporate all the best practices related to physical and cognitive training and game design (explained hereinafter). The solution was developed using Unity⁴, allowing support for multiple platforms (desktop, mobile, web).

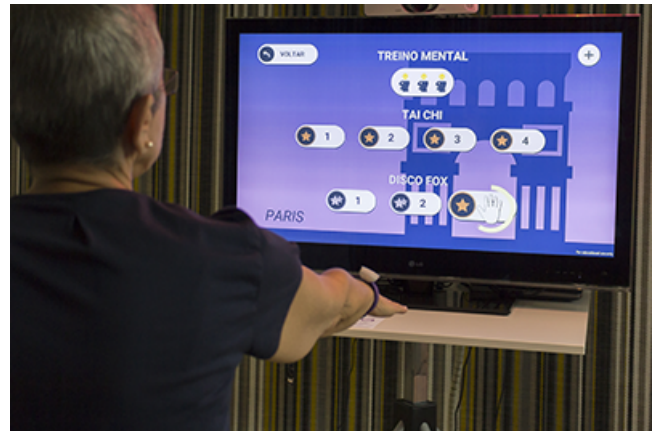


Figure 1: Game levels available in a city.

3.1 Motor-cognitive training

A multicomponent training for balance, strength and cognition was implemented, based on dance, Tai Chi and cognitive training. Besides challenging balance and strength, dancing and Tai Chi require cognition and mental engagement, being a promising form of intervention [17, 36]. When combined with explicit cognitive training for attention and executive functions, larger positive effects are expected on gait and functional abilities, necessary to prevent falls in the old age [2, 4]. To maximize the benefits for the users, training principles such as feedback, optimal load, progression and variability were incorporated. The last three principles were achieved by design, considering highly variable games with different levels evolving in load and difficulty. Movement and game performance feedback were given in real time using visual and auditory cues.

3.2 Game Design

To enhance the immersion and stimulate the player to move on through several challenges, the designed solution proposes a background narrative: a travel around the cities of Amsterdam, London, Paris, Porto, Rome and Zurich. In each city the player is able to i) perform a dance style, ii) practice Tai Chi, and iii) play *Brain Jogging* games (Figure 1). The travel is around the idea of a character, Arthur, who has an ambition to create an active center where older persons could improve their physical, mental and emotional health through dance and Tai Chi. An animated video introduces the character and his invitation to follow him in this adventure.

The user interface (UI) was designed so that: i) easy reading and good shape-understanding are ensured, e.g., appropriate font-type and font-size, distinguished shapes and adequate dimensions (to be displayed on a distant TV monitor), ii) the instructions are clear and easy to follow, and iii) the visual and sound feedback of the performance is obvious and assertive.

3.2.1 Dance. The developed solution proposes six dance styles: *Bachata*, *Cha-cha-cha*, *Disco Fox*, *Jive*, *Salsa* and *Waltz*. Each city is linked to one style with three difficulty levels. The performance occurs in a disco scenario where a trainer character (3D avatar) performs the intended movements (Figure 2-a) which the player has to mimic to get a score.

¹Sony Playstation[®], <https://www.playstation.com/en-ca/>, accessed July 27, 2018

²Microsoft Xbox, <https://www.xbox.com/pt-PT/>, accessed July 27, 2018

³Nintendo[®] Wii, <https://www.nintendo.pt/Wii/Wii-94559.html>, accessed July 27, 2018

⁴Unity 3D, <https://unity3d.com/>, accessed July 27, 2018

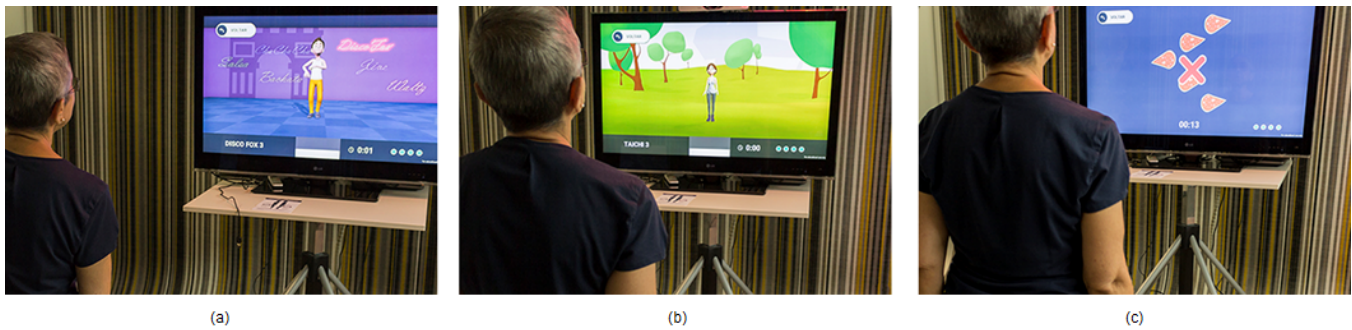


Figure 2: Playing motor-cognitive games: a) Dance scene, b) Tai Chi scene and c) A *Brain Jogging* game.

3.2.2 Tai Chi. Tai Chi practices happen in a garden scene (Figure 2-b). Again, the player has to mimic the movements of the avatar. Between movement sequences, and to balance the physical effort, the practice gives place to a short questionnaire – a Quiz with curiosities and general knowledge about the city where the player is. Each question has two possible answers, which are marked by tapping the right or left foot. Each city contains four or five difficulty levels.

3.2.3 Brain Jogging. These games aim at training cognition. They consist of different tasks to train reaction time, selective and divided attention, inhibition control, mental flexibility, visual spatial orientation and working memory. The player has to use steps in different directions, i.e. front, right, left and back, to properly answer to each challenge within the available time (Figure 2-c). At least three different games have to be played to advance to the next city.

3.3 Motion sensors and interaction

Four wearable sensors are needed to evaluate movement and interact with the game. Sensors are placed on the wrists and ankles using a slap-band mechanism (Figure 3). Bracelets are designed to be bio-compatible, comfortable and easy to wear. Bracelet color and size are used to disclose the correct positioning of the sensors on the body: while color is used to distinguish body side (i.e. right/left), size is used to distinguish arms and legs (Figure 3). Additionally, an arrow is drawn on the sensor's enclosure, to indicate the correct orientation of the sensor on the body, i.e. the arrow must be pointing to the hands or feet.

Each device contains an accelerometer, a gyroscope and a magnetometer. Raw data from the sensors are augmented through the application of sensor fusion techniques and data are transmitted to the computer via Bluetooth[®] Low Energy.

The sensor on the right wrist is used as a cursor, enabling the user to interact and navigate the game by pointing to the TV (Figure 4). To activate the cursor, the user has to point to the center of the screen, holding the arm steady and horizontal. Then, the user can navigate and select UI buttons by hovering them for 2-3 seconds. To deactivate the cursor, the user needs to point to the ground.

After selecting a dance or Tai Chi level, the player has to mimic the avatar movement. Data from the four sensors are collected and evaluated against movement templates representing the expected sequences of movement. The Quiz (from Tai Chi levels) and *Brain*

Jogging games are played using steps. The impact and orientation of the sensors on the ankles are evaluated in view of interpreting the direction of the step. Feedback is provided in real time and a score is presented reflecting player's performance.

4 METHODS

We assessed interaction and usability through usability-lab studies which consisted of having a participant in a lab, using the system individually in three daily sessions. A facilitator briefly presented the system requesting to each participant to execute specific tasks. Drawn on observation, post-test questionnaires and semistructured interviews were used to understand Perceived Usability, still the direct observation and participants' comments during their performance were revealing. Multiple sessions were required to assess usability in relation to learnability and memorability. The Ethics Committee of the University of Porto granted ethical approval (protocol number 46/CEUP/2018). All participants were fully informed prior to participation and signed a consent form.

4.1 Participants

An untrained elderly convenience sample was recruited from the city of Porto, Portugal, through Fraunhofer's Colaborar network. Participants were included if they lived independently, were older than 65 years old, were able to walk independently for 10-15 minutes and were healthy (auto-declared). Excluded were individuals with (1) mobility problems, (2) orthopedic or neurological diseases, (3) Alzheimer's disease or dementia, (4) pacemaker, (5) severe health problems, and/or (6) inability to understand the risks and benefits of the study. Eight participants were enrolled in the study, 6 females and 2 males, with an average age of 70 ± 3 years old.

4.2 Procedure

Participants tested the system in a controlled laboratory setting in three different sessions during three consecutive days, during which they had the opportunity to try different games with increasing difficulty. Each session took 20–30 minutes. All sessions were video recorded and all relevant aspects were annotated by a researcher-observer who observed participants' interactions and expressions. Participants were encouraged to "think aloud" while operating the software and playing the game. Each session consisted of a set of tasks described by another researcher-facilitator. A laptop was used



Figure 3: Wearing the sensors on the wrists and ankles.

to run the game which was connected to a TV. Participants were in front of the TV screen. The first task of each session consisted on placing the bracelets following a flyer with instructions. To properly do it, participants would need to correctly interpret bracelets' color, size and arrows. They would also need to properly position the sensor on the external lateral side of the leg (Figure 3).

4.2.1 First session. Participants were instructed to follow the UI to learn how to use the cursor and interact with the system. They were asked to start the game, select the city of Porto, and play the first level of Tai Chi. Then, they played a *Brain Jogging* game related to visual spatial orientation. After moving to Paris, they were invited to dance the first level of Disco Fox, and then go back to the main menu to turn off the system. To evaluate usability, the System Usability Scale (SUS)⁵ was applied at the end of the session.

4.2.2 Second session. Participants played the second level of Tai Chi (Porto) and dance (Paris). While in Paris, they have also played a *Brain Jogging* game for divided attention. The facilitator drove the participants to play a more autonomous role.

4.2.3 Third session. Participants played the third level of Tai Chi (Porto) and dance (Paris). The *Brain Jogging* game, on selective attention, was played in the city of London. To compare the results from the first to the last session, another SUS questionnaire was applied. Semi-structured interviews were conducted at the end of the session to assess perceived usability and attitudes towards independent use. Conversations were audio recorded, transcribed verbatim, and coded with thematic analysis to identify major themes [6].

5 RESULTS

5.1 User interaction

During the three sessions, we could observe the major difficulties and challenges of participants while interacting with the system. All difficulties, positive aspects and personal impressions were annotated.

5.1.1 Wearing the bracelets. Participants could understand by themselves almost all instructions/steps required to properly place the bracelets on the wrists and ankles, but at least one or two aspects had to be clarified by the facilitator. Most of them did not notice the arrows that were drawn on the sensor to indicate their correct orientation on the arms and legs. On the second and third sessions,

participants did not reveal any difficulty with placing the bracelets on the body. They all remembered how to use the arrows to properly wear the bracelets, and could do it with almost no intervention of the facilitator.

5.1.2 Using the cursor. Some participants could not immediately understand how to use the sensor as a cursor, and some additional instructions had to be given. They were not familiar with this kind of interaction, so, on the first attempt to click a button, some participants tried to physically touch the screen. After learning how to use it, some difficulties could still be observed.

While enabling the cursor, participants had difficulties maintaining the arm steady and horizontal, as they tended to point the arm directly to the button they wished to interact with. Because of this difficulty, some participants could hardly reach the buttons on the extremities of the screen. Immediately after activating the cursor, it was frequent to unintentionally click buttons that were placed at the center of the screen. A general feeling of a too fast cursor was also reported.

Despite the challenges, using the cursor became progressively easier. Participants recalled how to use it and, on the second session, all participants managed to avoid accidentally clicking buttons. Some participants suggested using the left arm to control the left side of the screen, as it would be more intuitive for them.

5.1.3 Navigation. Apart from the issues related to using the cursor, all participants could easily understand the UI and navigate to select cities, start different game levels, back to the main menu and turn off the system.

5.1.4 Dancing and doing Tai Chi. All participants could clearly understand and interpret the Avatar's movements. One participant commented that "*The Avatar does the movements very clearly and we can easily understand what he is doing*". Participants have also noticed and mentioned that the levels from the first to the third session were increasingly more difficult.

Two participants did not notice the graphical elements for movement feedback appearing in real time while they were playing: "*I could only focus on the Avatar*". All the others could notice them, but additional explanation was needed to clarify their meaning.

5.1.5 Answering the Quiz. During the first session, most participants had doubts on moving from the interaction with the cursor to the interaction with their feet. Participants tended to answer by doing steps to the right or to the left, which caused an unintended step to be detected each time the foot was back to the initial position. On the last session, this was not an issue anymore, as participants learned how to do it correctly.

5.1.6 Playing Brain Jogging games. Interaction with *Brain Jogging* games was particularly difficult for seniors. Not only some steps were not detected, step direction was not always correctly evaluated. Participants were not very rigorous with the stepping directions, and sometimes rotated the leg which caused the system to erroneously evaluate movement.

5.2 Perceived usability and user experience

Qualitative analysis and semi-structured interviews enabled to understand perceived usefulness, along with participants' attitudes

⁵A. I. Martins, A. F. Rosa, A. Queirós, A. Silva, and N. P. Rocha. 2015. European Portuguese Validation of the System Usability Scale (SUS). *Procedia Computer Science*, 67, 293–300



Figure 4: Game navigation using the right hand sensor as a cursor.

towards independent use, i.e. the use at home. Semi-structured interviews were coded in themes relative to health impact, target group, and benefits and barriers to use the technology at home.

All participants showed to understand the physical and cognitive impact of the exergame in terms of physical and cognitive training, expressing a positive feedback:

P7: *“All the exercise is good.”*

P3: *“[cognitive games] It helps to train the brain.”*

They found cognitive games quite challenging and good to train cognitive skills, however one participant stated that *“As steps are not always detected, I felt annoyed/angry”*. The positive effect of the Quiz has also been recognized, as *“It forces us to remember things.”*

Participants identified several target groups who would benefit for having the exergame at home. Older adults were clearly identified by all participants as the main target group. Additionally, they listed people who do not do physical exercise or do it a few times, or people who already perform some physical activity but could use the exergame as a support when they do not have time to go outside. They also indicated people who are at home and live alone as a potential target group:

P3: *“This [exergame] could be a support for me [who already do exercise].”*

P5: *“Nice [exergame] for people of my age.”*

All participants stated that the exergame could help someone who does not know how to exercise to perform the exercises correctly due to the presence of the avatar, which was perceived simultaneously as a teacher and as a companion. They also recognized the exergame as a fun way to perform exercises which they felt to be important to motivate people of their age:

P8: *“The avatar explains very well what we have to do. [Avatar] guides people who do not know the exercises.”*

We could observe that almost all participants were smiling while playing and were often commenting that games were enjoyable and fun. The main obstacle and barrier identified by participants was older adults being agnostic to this type of technology. Half of the participants felt that some people could experience difficulties

in interacting and navigating the game without any help. However, the remaining participants did not show any concerns.

A SUS global score of 78.8 ± 11.5 was obtained in the first session, and increased to 89.7 ± 8.2 in the last session. Even though these scores characterize a highly usable and acceptable system, it should be noted that participants had several doubts on how to interpret and answer some items of the scale.

6 DISCUSSION

Overall, participants enjoyed the games, and recognized their positive impact on physical and cognitive health. They considered our solution to be useful for all older adults who wanted to stay healthy and live independently, having the avatar as a coach and as a companion.

Participants supported the use of the technology at home, however, they noticed that some people would experience difficulties in interacting and navigating the game without external help. This finding is supported by the difficulties they had when they started using the system for the first time, which required learning new forms of interaction they were not familiar with. This was also a common problem of existing solutions [32]. It is then crucial to improve in-game instructions on how to interact with the system and guide this interaction to avoid its misunderstanding, which is particularly relevant if the game is to be played independently at home.

Despite these observations, the evolution on the quality of the interaction between the first and the third session was quite obvious. Interaction was progressively easier and more intuitive, particularly in relation to placing the sensors on the body and using the cursor. Despite these advances, a strategy to avoid unintentional clicks should be implemented, to enhance interaction from the very first contact with the technology. Apart from these issues related to using the cursor, all participants could readily understand the UI and navigate through cities to select new game levels or turn off the system. Contrarily to what was reported in previous studies ([1, 20, 32]), speed and complexity of the UI was not an issue.

The SUS score was in line with these observations, however, as participants had doubts on how to interpret and answer some items, we questioned about the value of the score in the context of games for older adults. In fact, the Portuguese version of the SUS was validated with a younger sample (average age of 47 ± 15 years old), which may partly explain these observations.

Participants could not understand or notice the feedback mechanisms employed while dancing or doing Tai Chi. Even though we tried to place these graphical elements as close as possible to the main action of the game, players were focused on following the movement of the avatar and ignored the secondary visual elements. Further tests must be carried out to validate and, if necessary, improve these feedback elements required to help participants identify their errors and learn. Still, a good tutorial should be provided to explain the meaning of these elements.

A particularly challenging interaction problem was related to the detection of steps to play *Brain Jogging* games. These movements were not always correctly evaluated, which created some discomfort and a bad interaction experience. This is a critical aspect of our solution that needs to be worked to make step detection and

direction evaluation more robust to the different configurations of steps and amplitude of movements. Despite the issues, participants enjoyed the games.

It is worth mentioning that in this study a relatively small number of participants were included, so careful interpretation and generalization of results is necessary.

7 CONCLUSION AND FUTURE WORK

An exergame for motor-cognitive training and fall prevention in older adults has been developed, including a diversity of tasks and means of interaction. Older adults enjoyed the games and, despite the challenges, they were able to learn new forms of interaction, that gradually became more intuitive. In-game strategies to support interaction were considered as a promising step forward, fundamental to encourage autonomous and easy use of the technology. We intend to continue improving interaction and in-game support strategies, as they reflect a promising solution for multicomponent home-based training in older adults.

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