computers

Article

Feasibility and Acceptance of Augmented and Virtual Reality Exergames to Train Motor and Cognitive Skills of Elderly

Christos Goumopoulos [1,*], Emmanouil Drakakis [1] and Dimitris Gklavakis [2]

[1] Information & Communication Systems Engineering Department, University of the Aegean, 83200 Samos, Greece
[2] Depia Automations, 56238 Thessaloniki, Greece
* Correspondence: goumop@aegean.gr

Abstract: The GAME2AWE platform aims to provide a versatile tool for elderly fall prevention through exergames that integrate exercises, and simulate real-world environments and situations to train balance and reaction time using augmented and virtual reality technologies. In order to lay out the research area of interest, a review of the literature on systems that provide exergames for the elderly utilizing such technologies was conducted. The proposed use of augmented reality exergames on mobile devices as a complement to the traditional Kinect-based approach is a method that has been examined in the past with younger individuals in the context of physical activity interventions, but has not been studied adequately as an exergame tool for the elderly. An evaluation study was conducted with seniors, using multiple measuring scales to assess aspects such as usability, tolerability, applicability, and technology acceptance. In particular, the Unified Theory of Acceptance and Use of Technology (UTAUT) model was used to assess acceptance and identify factors that influence the seniors' intentions to use the game platform in the long term, while the correlation between UTAUT factors was also investigated. The results indicate a positive assessment of the above user experience aspects leveraging on both qualitative and quantitative collected data.

Keywords: augmented reality; virtual reality; exergame; elderly; Unified Theory of Acceptance and Use of Technology (UTAUT); user experience; evaluation study; fall risk

Citation: Goumopoulos, C.; Drakakis, E.; Gklavakis, D. Feasibility and Acceptance of Augmented and Virtual Reality Exergames to Train Motor and Cognitive Skills of Elderly. *Computers* **2023**, *12*, 52. https://doi.org/10.3390/computers12030052

Academic Editors: Tayeb Lemlouma, Yevgeniya Kovalchuk, Sébastien Laborie and Abderrezak Rachedi

Received: 30 January 2023
Revised: 22 February 2023
Accepted: 24 February 2023
Published: 27 February 2023

1. Introduction

Exergames are a type of game that requires physical activity in order to play. These games may use motion-sensing technology, such as a Kinect or Wii remote, to track the player's movements and respond to them in the game [1]. Exergames are designed to provide an engaging and interactive way to exercise, and are aimed at promoting physical activity in a fun and entertaining way. Over the past several years, exergames have been extensively used in training motor and cognitive skills in older adults [2]. In particular, exergames can help improve balance and coordination, which are important factors in fall prevention [3,4]. Falls are a leading cause of injury among older adults and can have serious consequences, including physical injuries, loss of independence, reduced quality of life, and increased healthcare costs [5].

Augmented and virtual reality (AR/VR) can be used in the context of the exergames to train motor and cognitive skills in the elderly population for health improvement [6]. For motor skills training, VR can be used to provide immersive simulations of tasks that may be difficult for older adults to perform in the real world, such as climbing stairs or reaching for objects [7]. This can help improve their physical function and mobility [8]. For cognitive skills training, AR and VR can be used to provide interactive and engaging exercises that target specific cognitive abilities such as memory, attention, and problem solving [9,10]. These exercises can be designed to be both fun and challenging, making them more likely to be used by older adults. Additionally, AR and VR can be used to provide social engagement, which is important for older adults, as well as provide a way to simulate real-life environments, which can be beneficial for older adults with mobility issues [11,12].

Commercial VR exergames that target a range of physical capabilities, including balance and strength, have been used in studies to improve physical function in older adults, including balance, gait, and upper and lower body strength [13]. However, there are several challenges that have been reported with the use of commercial VR in formal rehabilitation [14,15]. Some of these include the complexity of technical setup, VR sickness (such as nausea or dizziness) caused by the immersive nature of the technology, and the suitability of the technology for older populations who may have difficulty using or adapting to the technology [16].

Commercial exergames, like many other video games, are often designed for a general audience and may not take into account the specific needs and abilities of the elderly population [17,18]. This can include factors such as the level of difficulty, the type of physical movements required, and the interface design [19]. For example, some exergames may require quick reflexes and fast movements, which can be difficult for older adults with decreased mobility or coordination. Other exergames may have complex interfaces or controls, which can be difficult for older adults with visual or cognitive impairments. Therefore, it is important that exergames for seniors are age-appropriate and take into account the physical and cognitive abilities of older adults. This can include designing games that are not too fast-paced, have simple controls, and provide clear visual and audio cues.

In this work, concrete evidence is provided on the feasibility and acceptance of exergames developed within the context of the GAME2AWE platform. GAME2AWE leverages a participatory game design approach in order to take into account the knowledge of the relevant stakeholders and combines AR and VR technologies in order to provide a versatile tool for training the motor and cognitive skills of the elderly as a fall preventive measure. The AR exergames that were created involve exploring scenarios on mobile devices, such as tablets and smartphones, where game content is superimposed onto real-world surroundings. While this approach has been previously investigated in physical activity interventions for younger individuals [20], its effectiveness as an exergame platform for the elderly has not been adequately studied, to the best of our knowledge.

An evaluation study was conducted with seniors to investigate whether the AR/VR exergames are acceptable and engaging. For the elderly, the most important question was whether they would embrace such modern technologies in the context of exergames. In the performed study, multiple measuring scales were applied to assess different aspects of the game platform, such as usability, tolerability, applicability, and technology acceptance. For the latter, in particular, the Unified Theory of Acceptance and Use of Technology (UTAUT) model is used to assess the acceptance and identify the constructs that influence the intentions of the elderly to use the exergames in the long term. The correlation between the UTAUT factors is also investigated to provide insights into how the different factors interact and impact each other, and which factors are most important in shaping user intentions and behavior.

2. Background

2.1. Elderly Falls and Physical Exercises

As individuals age, alterations in the sensory, motor, and cognitive systems can impede their ability to regulate balance, making it arduous to generate an appropriate reaction to balance perturbations [21]. This, in turn, can increase the likelihood of experiencing a fall [22]. Falls are a significant health risk for elderly individuals, and research indicates that a noteworthy proportion of falls (ranging from 5% to 20%) result in severe outcomes, including head trauma, fractures, and, in severe cases, immobility or fatality [23]. Apart from the individual implications, falls have a substantial economic impact on both healthcare systems and society at large. The costs associated with falls are estimated to account for between 0.85% and 1.5% of the total healthcare expenditure in several countries, including the United States, Australia, the United Kingdom, and the European Union [24].

In community-dwelling older adults, difficulties with maintaining balance have been identified as a key contributor to the elevated risk of falling [25]. Falls often transpire in circumstances that disrupt postural stability, such as when individuals are turning or reaching, or during walking activities [26]. As such, impairments in postural control can have far-reaching effects on an individual's ability to move around safely and effectively, limiting their mobility and independence [5]. The significant rise in the incidence of falls among older adults highlights the urgency of prioritizing research aimed at preventing such incidents as a crucial public health issue. Previous investigations have demonstrated that interventions aimed at enhancing the physical capabilities of older individuals can result in a substantial reduction of up to 50% in the risk of falling [27].

Research conducted in the past several years has consistently demonstrated that balance exercises are a crucial component of effective exercise programs for older adults in reducing the risk of falls [3]. These exercises focus on improving neuromuscular control, postural stability, and the ability to respond to balance perturbations. As a result, fall prevention programs for older adults should incorporate exercises that challenge balance and target these abilities. Such exercises should focus on reducing the base of support, shifting the center of gravity, and reducing the reliance on upper limb support [28]. These types of exercises have been shown to improve balance and reduce the risk of falls in older adults, underscoring the importance of including them in fall prevention programs.

The World Health Organization (WHO) recommends 150 min of moderate aerobic activity weekly and also highlights the importance of incorporating physical activities that enhance balance and increase muscle power for seniors with limited mobility [29]. Engaging in such exercises three times per week has been shown to reduce the risk of falling by up to 30% [30]. Balance exercises include standing on one leg, walking heel-to-toe, and standing on a balance board. Strength training exercises include squats, lunges, and leg presses.

According to research, stepping exercises have been proposed as a potentially effective intervention for improving balance in older adults [31]. It has been demonstrated that older adults who engage in a regular exercise program, which incorporates stepping exercises, can experience notable enhancements in both balance and overall physical health. Similarly, stepping or walking exercises have been recommended by major health organizations such as the WHO as an effective means of promoting physical activity and reducing the risk of falls in older adults [29].

Therefore, incorporating a combination of aerobic, strength, stepping, and balance-enhancing exercises into an older adult's routine is essential for promoting overall physical health and reducing the risk of falls.

2.2. Literature Review

Exergames can help with balance recovery and can alleviate the danger and frequency of falls, according to recent studies [32,33]. Exergames, which combine physical and cognitive tasks, can increase motor-cognitive function, a person's level of independence, and their adherence to therapy [2,34]. In order to lay out the research area for the proposed GAME2AWE platform, a review of the literature on systems that provide exergames for the elderly utilizing AR and VR technologies was conducted.

With the aim of reducing the incidence of falls among elderly persons, a system for AR-based exergames was developed using the Kinect 2.0 sensor and interactive virtual environments in which 3D representations of the users were placed [35]. Three game scenarios were supported by the system. In the first scenario, players must position themselves correctly to pass through a gap in a wall that is moving in their direction. The second involves fruit harvesting by asking the players to move in the direction of the appearance of the fruits. In the third scenario, rats are squashed as they emerge from soil-penetrated burrows using gait movements. The system is designed to help players improve their muscle strength, as well as their motor and cognitive abilities. The physical activities involved are also beneficial for practicing balance. In a study involving 25 elderly people over the age of 65, the system was assessed positively in terms of user experience.

In a different study, the needs and requirements for an exergame platform aimed at senior people with underlying health issues such as hypertension were investigated using exergame prototypes with activities conducted in both AR and VR contexts [36]. The elderly had no memory or balance issues. A couple of exergames required seniors to squat in a VR or AR environment workout zone. Critical system technology, monitoring, and gamification requirements were determined by analyzing qualitative data gathered through interviews. In terms of gamification, the participants require the ability to evaluate their performance in relation to their prior results after finishing the game tasks. Participants thought the game's narrative component was crucial, and they preferred watching a video demonstration over reading a handbook to learn how to play. A smart band was used to track player health information during the game, such as heart rate.

Utilizing the Internet of Things and AR technologies, a scenario-based exergame prototype with gamification components was developed [37]. As a proof of concept, a couple of exergame scenarios were produced. In the first example, the player must ascend a staircase by stepping with high knees. In the second scenario, the mission is to fly like a parrot in a canyon environment which requires the player to make the proper shoulder and elbow movements. In order to measure variables such as heart rate and balance for potential fall detection, a smart wristband and foot pressure sensors controlled by an Arduino board were also integrated into the system. Three individuals participated in user testing of the prototype, and their feedback will be applied in the following development cycle.

The development of AR and VR exergames aimed at rehabilitating seniors with balance issues, along with their design and applicability topics, were discussed in a relevant study [38]. A balloon popping exergame was created in a variety of immersive AR and VR configurations in order to grasp the key design considerations and enable its evaluation by physicians for suitability in reducing fall risk. In the case of the VR version, moving around the scene is necessary to touch ascending balloons. In the case of the AR version, simple hand movements are sufficient. The exergame is played using the proper headsets in both settings. The results of the evaluation point to both a promising outlook and the need for technical advancements, such as the use of more practical headsets and the inclusion of new physical and cognitive activities.

In order to co-develop VR exergames to engage elderly people with dementia in physical practice that fosters upper limb elasticity, muscle strength, and endurance, a participatory design approach was used with the involvement of relevant stakeholders, including demented elderly, exercise experts, researchers in the development of VR-based exergames and content developers [39]. Seas the Day is a VR exergame developed in this context that immerses users in a tropical virtual reality setting and requests them to complete three tasks in 15 min. To warm up, the participants perform Tai Chi exercises. Next, they perform activities involving rowing to train their muscles. Finally, they engage in fishing, which requires neck rotations and elbow movements. An evaluation study was performed to assess user experience with the participation of five elderly people who live in the community. In addition to playing the exergame, participants helped define a protocol for remote deployment and system evaluation.

A prototype exergame was created to help therapists motivate senior patients recovering from mild strokes during training sessions, while also allowing for the evaluation of VR technology usage in terms of motor and balance recovery [40]. The exergame integrates six activities immersed in a scenario that calls for interacting with virtual objects positioned across the user's environment. The upper limbs are trained in half of the activities, with movements of the elbows, wrists, and shoulders. The other half of the activities help patients improve their balance by exercising the lower limbs through appropriate hip movements. The user movements made while playing the game were detected and mapped using the Kinect sensor. A pilot study was carried out to evaluate the user experience using various visualization tools and test the overall exergame functionality.

An approach of simultaneous motor-cognitive training in a VR environment, and a study investigating the effects of this approach in older adults, are presented by Kwan et al. [41]. Results indicate that cognitive function was improved in both the experimental group and the control group. However, a greater improvement in cognitive function was observed in the experimental group. This group engaged in activities that integrated motor and cognitive functions, primarily performed simultaneously. These activities were designed to simulate daily tasks commonly performed by older adults in Hong Kong, such as finding a bus stop, reporting lost items to the police, finding a supermarket, grocery shopping, finding a travel hotspot, and bird watching. Additionally, the experimental group participated in an activity that exclusively required cognitive function, such as cooking. In this cooking task, participants were instructed to flip eggs at a predetermined time interval. This task required mental processing speed, which was quantified by measuring participants' reaction times. The reaction time served as an indicator of the cognitive demands and mental workload involved in the task, as it reflects the time it takes for participants to process and respond to the visual and auditory cues related to the task requirements. The experimental group was equipped with a VR screen and VR controls, as well as an under-desk pedal exerciser (DeskCycle 2) and a heart rate sensor (Polar OH). On the other hand, the control group performed the cognitive and motor exercises sequentially in a non-VR environment, utilizing a Windows tablet and an under-desk pedal exerciser.

Finally, the research by Xu et al. [42] investigates the acceptance of VR exergames with the use of an extended version of the Technology Acceptance Model (TAM). The acceptance of exergames among elderly Chinese individuals is the focus of the study. In the study, participants had to play three commercial exergames (Beat Saber, FitXR, Dance Central). The study examines the relevant constructs or variables, which include the extension of TAM constructs, such as Perceived Usefulness, Perceived Ease of Use, and Intention to Use. Recommendations were provided through the use of the survey results for developers of exergames for Chinese elderly individuals. The need to emphasize the health benefits of exergames for the Chinese elderly is highlighted by the research, as well as the importance of adapting cultural features of the game, such as Chinese songs and traditional dances, to the target group.

Older adults were the target user group for all the studies examined. In terms of hardware, the majority of AR games employed the Kinect motion sensor to track the user's motions. VR controllers were frequently used to handle motion sensing in VR games. In several studies, the exercises involved both upper and lower body activity and were combined with cognitive elements. Several studies have also focused on balance training with appropriate exercises. The critical points of the literature analysis are presented in Table 1.

Our work shares some basic objectives and practices with other studies, such as the combination of multiple enabling technologies to develop exergames that are specifically designed for the elderly population. Regarding the combination of AR and VR technologies, a considerable difference in this work is that the relevant exergames are provided under an integrated environment with a rich data collection functionality. This enables the provision of smart services such as dynamic difficulty adjustment of the games and post hoc data analysis for health assessment. Furthermore, for the AR exergames developed, besides the traditional Kinect-based approach, AR scenarios are explored on mobile devices (i.e., tablets and smartphones) with game content that is superimposed on the surroundings of the real world. This is an approach that has been examined in the past with younger individuals in the context of physical activity interventions [20], and to the best of our knowledge, it has not been studied adequately as an exergame platform for the elderly. Finally, to assess the feasibility and acceptance of the AR/VR exergames developed to train the motor and cognitive skills of the elderly, a comprehensive evaluation study with multiple measuring scales is provided, and the factors influencing the acceptance of the GAME2AWE platform are highlighted.

Table 1. Key elements of the explored AR/VR exergame systems.

Work	Type	Main Equipment	Test Sample	Activities	Assessment
[35]	AR	Microsoft Kinect 2.0, TV	25 (16 F, 9 M), age 71.5 ± 4.1	Avoid walls (muscle training, balance); pick fruits (muscle training, balance); stop rats (gait training).	User experience
[36]	AR, VR	Microsoft HoloLens, HTC Vive	11 (6 F, 5 M), age 65–91, MMSE ≥ 24	Squatting (in AR and VR settings); seated trunk rotation (in a VR setting).	Qualitative study for requirements analysis
[37]	AR	Microsoft Kinect 2.0, Arduino	3 (1 F, 2 M), age 43–62	High knee walking on the spot; shoulder and elbow movements.	Proof of concept prototype testing
[38]	AR, VR	Samsung HMD Odyssey, Cyberith ODT, Meta2 ARH	11 physiotherapists	Balloon popping (in AR and VR settings)	Safety, acceptability, and applicability
[39]	VR	Oculus Quest 1 and 2	Stakeholders; 5 healthy older adults	Tai Chi movements (warmup); rowing (muscle training); fishing (neck rotations, elbow flexion, elbow extensions).	Participatory design; User experience
[40]	VR	Oculus Rift, TV, Microsoft Kinect 2.0	10 (8 F, 2 M), age 61–75	Three exercises for upper limbs; three exercises for lower limbs (and balance)	User experience
[41]	VR	HTC VIVE Focus Plus, DeskCycle 2, Polar OH	17 (15 F, 2 M), age ≥60	Eight daily living tasks, six/eight simultaneously required motor and cognitive function	Physical and cognitive performance
[42]	VR	Oculus Quest 1	51 (29 F, 22 M), age ≥65	Commercial VR exergames (FitXR, Beat Saber, and Dance Central)	Technology acceptance
this work	AR, VR	Microsoft Kinect 2.0, ARCore, Oculus Quest 2	23 (16 F, 7 M), age ≥65, 4 domain experts	Eighteen exercise types integrated into two scenario-based exergame themes, “Life on a Farm” and “Fun Park Tour”	Usability, tolerability, applicability, technology acceptance

ARH: Augmented Reality Headset; HMD: Head-mounted Display; F: female; M: male; MMSE: Mini-Mental State Examination; ODT: Omnidirectional Treadmills.

3. Materials and Methods

3.1. GAME2AWE Platform

The work presented in this work is part of the GAME2AWE platform, which was developed with the aim of supporting motor and cognitive training of seniors through properly designed exergames. The platform integrates AR and VR technologies with intelligent software to create adaptable gaming experiences [43]. A specific objective of GAME2AWE is to analyze the data collected during the gameplay by applying machine learning techniques in order to adapt the exergame activities by dynamically adjusting the game difficulty [44].

The design and development of the GAME2AWE platform were based on the principles of participatory and human-centered design [45]. For the development of exergames, an initial list of potential games was assembled in the form of themes, basic features, integration of appropriate exercises, and operating rules, after analyzing the relevant literature and leveraging on our own experiences [46]. Next, representative scenarios were selected to meet the GAME2AWE objectives and presented for feedback to end users and healthcare experts within a focus group [47]. The data collected from the workings of the focus group were analyzed to derive the basic guidelines and to record issues that needed attention in the development of the games.

During the design of the exergames, the topic of selecting exercises that are appropriate for fall prevention was also explored. Recommendations that have been proposed as guidelines for physical exercising by organizations such as the WHO [29] as well as from the relevant literature [48] were reviewed. The exercises to be used in the mechanics of the games were identified and organized into three main categories: aerobic exercises (e.g., walking on the spot), strength-enhancing exercises (e.g., rowing), and balance-enhancing exercises (e.g., single leg side lift). In total, 18 exercise types were designated, including, amongst others, walking on the spot in standing or sitting position, rowing in standing or sitting position, weight shifting in standing or sitting position, stepping forwards, backward, and sideways, standing on one leg, squatting, flank stretching, etc. Thus, the research hypothesis is that integrating proper physical exercises in exergame scenarios using AR and VR as enabling technologies can provide a motivating tool for physical and cognitive stimulation of the central nervous and musculoskeletal system of elderly people to reduce fall risk.

GAME2AWE proposes a combination of AR and VR technologies providing the user with a greater variety of exercises and immersive interactions. Such interactions can facilitate the implementation of game scenarios in a way that motivates and enhances users' engagement while making the platform easy to use. Motivation is also served by implementing gamification elements such as scenario-based tasks, difficulty levels, challenges, points, leader boards, avatars, and target randomization. Furthermore, the platform includes a smart floor as a complementary low-cost and configurable device to support additional exergaming experiences [49].

Currently, the GAME2AWE platform includes 15 games organized into two themes: "Life on a Farm" and "Fun Park Tour". The former includes activities that are themed around farming tasks such as seeding and fertilizing a field, crop harvesting, insect repelling, and selling crops or purchasing resources. This theme is implemented using AR technology. On the other hand, the "Fun Park Tour" includes exergames that immerse players in a fun park with activities that require physical and cognitive skills. These games are implemented using VR technology.

3.1.1. AR Games

AR can offer a high level of embodiment and a sense of spatial presence regarding user experience. Together, these characteristics can create a very immersive and realistic experience for the user, making it feel as if they are truly present in the virtual environment. Microsoft Kinect sensor was used to capture 3D models of the elderly and embody them in interactive virtual environments based on the "Life on a Farm" theme. This device uses infrared and RGB cameras, as well as a microphone array, to sense the movements and gestures of people in its field of view. The exergames are developed by tracking the movements of the player and using that information to control the game. The sensor can detect the player's body position, limb movements, and gestures, allowing for a wide range of exercises to be incorporated into the game, such as arm and leg movements, balance exercises, and even more complex movements such as dancing.

In GAME2AWE, the second version of the Kinect sensor was used, which is enhanced with improved skeletal tracking, better low-light performance, and the ability to track multiple players at once with a richer SDK API. To recognize game activities, a training process was carried out using a motion recording tool and machine learning algorithms supported by the Kinect SDK. The Kinect Studio tool was used to observe how the sensor captures the environment in order to build the activity model. This tool also made it quicker to record game mechanics' movements and gestures.

One issue that required attention during the training process was the fact that different elderly people have different body sizes. As a result, when trained on a small number of people, the system was unable to recognize gestures and movements effectively. Furthermore, it is expected that older people will not perform a specific movement in the same manner as younger people. It is expected, for example, that older people will not lean left or right in the same way. To address this issue, a focus group was formed with the participation of eight elderly people of varying weight/height, who were asked to perform each activity of the games in order to record and store the movement patterns as multiple samples.

Snapshots of two example exergames implemented with the Kinect technology are shown in Figure 1. In the "Healthy Garden" game, the player's task is to handle a variety of insects that may either harm or benefit garden plants. The player is guided to use stepping movements (i.e., left/right sideways steps and forward/backward steps) to eliminate the hazardous insects. In the "Olive Harvest" game, the gameplay mechanics integrate movements that were chosen as suitable exercises for fall prevention while also serving a specific gameplay objective. Side steps are utilized, for instance, to choose which tree to harvest. Spreading the olive collection sheet requires a rowing motion, whereas harvesting requires arm lifting.

(**a**) (**b**)

Figure 1. Snapshots from two desktop AR-based (Kinect-based) exergames in the "Life on a Farm" theme: (**a**) "Healthy Garden" game; (**b**) "Olive Harvest" game.

The user interface of the games is kept minimal, and only the relevant information and components are shown. Consistency is also crucial; thus, the vitality bar is always displayed on the left side of the screen, and the points obtained are always presented in the upper right corner. The former component is a visual representation of the physical activity progress based on the activities completed during gameplay.

A mobile AR application that blends the real world with virtual objects is used to explore some of the farming activities. Ray casting with a bounded range is used to find objects that have spawned in the space of a room. The user must therefore approach and reach the various objects in order to interact with them. Because the objects are not always immediately visible, some activities may require supplementary movements. Figure 2 presents snapshots of activities performed in the mobile AR-based exergame.

(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

Figure 2. Snapshots of activities in the mobile AR-based exergame in the "Life on a Farm" theme: (**a**) purchase of seed sacks; (**b**) purchase payment; (**c**) collection of seed sacks; (**d**) collection of fertilizer sacks; (**e**) reading water meter; (**f**) crop harvesting.

As an example, the activity purchase of seed sacks displays on the floor a four-sided rack base with two rows of shelves on each side of the base. The player must move in a circle around the virtual rack base, bending where necessary, to inspect and select the proper seed sacks (Figure 2a). When all the specified seed sacks have been marked, a payment interface appears. To complete the purchase payment activity, the player must solve a simple arithmetic payment operation by selecting the right amount of money corresponding to the calculated cost (Figure 2b).

As another example, during the collection of fertilizer sacks, the floor is augmented with a predetermined number of fertilizer sacks as well as other sacks containing irrelevant resources such as animal feed, lime, and charcoal (Figure 2d). To collect the fertilizer sacks, the player must approach them and use the camera of the mobile device to aim at them. The label on the sacks and the texture on their open top can be observed in order to identify the fertilizer sacks. The number of objects that are visualized on the ground varies according to the difficulty level.

Motor skills trained in such activities include walking in the room, movement coordination, bending, or squatting. Cognitive skills involved include visuospatial orientation, attention, and short and working memory. Table 2 provides an overview of the motor and cognitive skills that are trained by the AR activities.

3.1.2. VR Games

Oculus Quest 2 technology by Facebook Reality Labs was used to develop the VR games. The Oculus Quest 2 is a standalone wireless VR headset with a low weight of about 500 g without requiring a base game station to operate, making it more convenient for older adults to use. It has a high-resolution display, which can provide older adults with clear and crisp images, making it easier to read text and see details in the virtual environment. It also provides an inside-out tracking system that allows for a greater degree of freedom of movement, which can be beneficial for VR exergames that focus on balance and coordination. Its operation requires two controllers for motion detection and a WiFi network. A game area of approximately 5 m^2 was tagged in accordance with the manufacturer's suggestions.

Table 2. Summary of motor and cognitive skills trained with the AR activities.

Activity	Motor Skills	Cognitive Skills
Purchase of seed sacks	Walking in the room Walking in a circle Movement coordination Bending	Visuospatial orientation Attention Short memory Working memory
Collection of seed sacks	Walking in the room Movement coordination Bending	Visuospatial orientation Attention Short memory
Collection of fertilizer sacks	Walking in the room Movement coordination	Visuospatial orientation Attention
Reading water meter	Walking in the room Bending/squatting	Visuospatial orientation Attention Short memory Working memory
Crop harvesting	Walking in the room Movement coordination Bending	Visuospatial orientation Attention

The VR-based exergames developed require moving the upper or lower limbs or moving around the game area to interact with virtual objects via the controllers. Example games are shown in Figure 3 and outlined briefly in the following. The "Whack a mole" game, in which the goal is to stomp the moles away when they appear in random positions. The "Bazaar" game, in which the purpose is to find the right toy among a variety of objects that are in front of the players' bench and give it to a customer within a certain time. Lastly, the "Darts" game, in which the player is asked to throw and burst in a certain order 12 balloons, 6 of which are numbers and 6 are letters of the alphabet. In order to break a balloon, it is enough to look at it for a short time and center the central cross on the game screen. When the targeting is complete, the arrow is released to hit the desired balloon.

(**a**) (**b**) (**c**)

Figure 3. Snapshots from three VR exergames in the "Fun Park Tour" theme: (**a**) "Whack a mole" game; (**b**) "Bazaar" game; (**c**) "Darts" game.

All VR games have been designed with older adults in mind, with features such as larger text, simple navigation, and easy-to-use controls. In order to be engaging and interactive, games integrate immersive graphics, sound effects, and physical interaction that can keep users motivated and interested in the game [50]. Games also support customization by adjusting the difficulty level or selecting different environments to suit their individual needs.

3.1.3. Data Storage and Analysis

In the development process of the exergaming platform, a data model was created that describes the fundamental abstract concepts needed to run the exergames and the relationships between them. Figure 4 depicts this model in the form of a UML class diagram. For instance, the model includes the "Subject" class that represents a player with attributes such as identifier, gender, age, and education. Additionally, the "Preference" class allows for personalization of specific game elements. A player can participate in single or multiple-player games within a session, which is associated with a specific user login. Games can have physical and/or cognitive training characteristics, and movements made by players during gameplay are recorded for later analysis. Assessments of motor and cognitive functions are also stored as class labels that can be used by machine learning algorithms. This data model serves as the basis for the entities and attributes that will be stored in the platform's database for real-time and post hoc data analysis. Such analysis can help identify patterns, trends, and insights from the data, which can inform decision making and help improve the exergaming platform's performance and user experience.

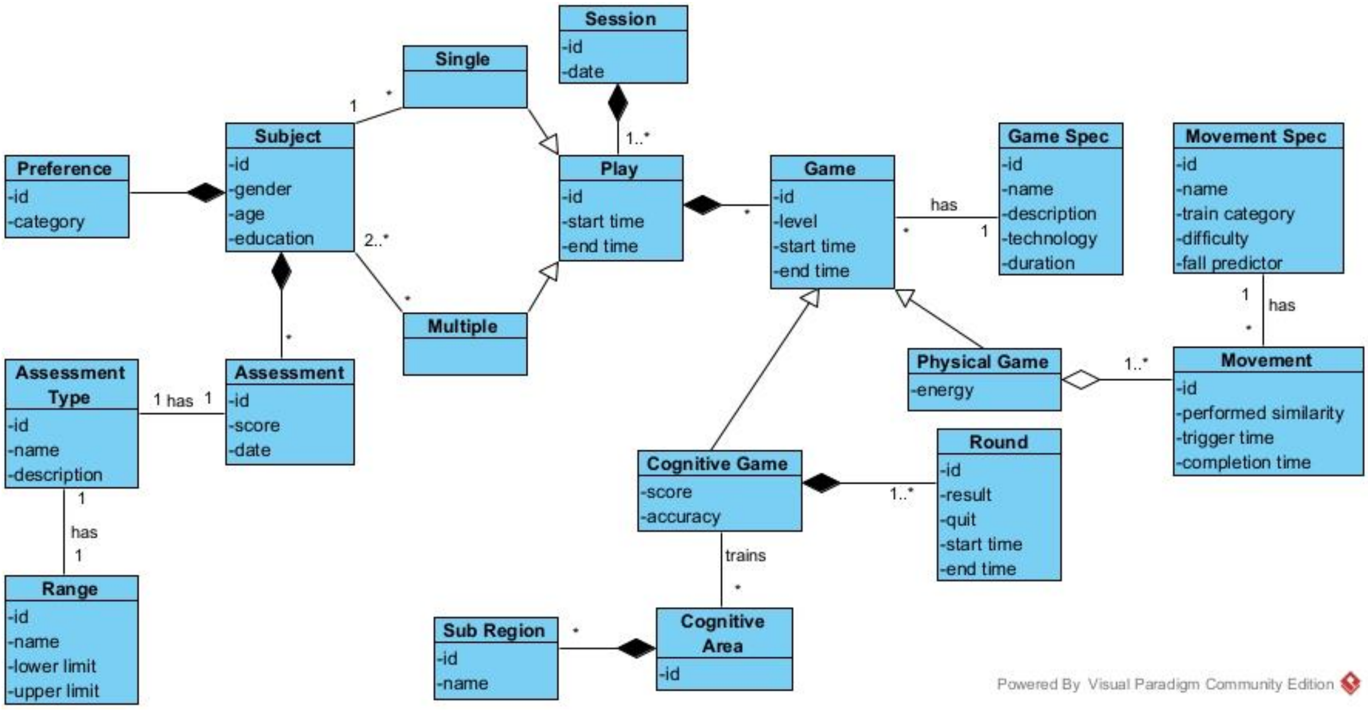

Figure 4. GAME2AWE platform data model in UML notation.

The system gathers and maintains performance data during platform usage, including game scores, interaction times, frequency of use, games completed successfully, faults encountered, etc. The suitable level of exercise difficulty for each user can be subsequently determined individually using the recorded data and machine learning algorithms [44].

A database schema is established based on the domain model of the GAME2AWE platform, which maintains game data and user performance for the support of the adaptation layer as well as the support of screening processes. In the latter case, patterns found in the stored data can be used to determine a subject's cognitive and physical abilities, thereby enhancing or perhaps replacing associated conventional diagnostic techniques.

Furthermore, the analysis of the collected data that are associated with validated metrics can provide useful predictors. For example, incorporating into the game mechanics tests that have been shown to predict fall risk, such as the Choice Step Reaction Time (CSRT) test [51], can promote the platform as a diagnostic tool. In such a case, subjects are asked to perform as quickly as possible stepping actions in response to the corresponding random visual stimuli presented in the game scenario. CSRT time is measured in milliseconds and corresponds to the time from the presentation of the stimulus to the rising of the foot and the contact of the foot on the presented target. The structure of the CSRT test, as presented, makes it suitable for integration into the "Healthy Garden" AR exergame, where the goal is to repel insects that appear randomly in different positions by stepping towards them at the right time. A number of such trials are required (e.g., twenty), which are equally distributed for each one of the various possible stepping reactions. The analysis includes all trials to balance out any potential predictions about which foot is needed for each step. In the analysis, the average time of the trials is used. Studies have shown that when compared to stable elderly, fall-susceptible elderly have significantly longer CSRT times [51].

3.1.4. Implementation Tools

The desktop AR-based exergames and the VR-based exergames were developed using Unity Engine 2020.3.14, Microsoft Visual Studio 2022 CE, the C# language for programming the interactivity and logic and assets from the Unity store such as the Gaia Manager for terrain and scene generation. The mobile AR application was developed using Unreal Engine 4.27.2, which provides another popular rapid prototyping platform for games with Blueprints visual programming and the Google ARCore libraries (v. 1.18.0) for Android. Android mobile devices were preferred as the target devices due to their low cost and pervasive use compared to other AR solutions. It is possible to develop mobile AR-based exergames for the iOS operating system using the Unreal Engine 4.27 software platform, which supports the creation of AR games for iOS devices. In this case, the developer must set up the iOS developer certificate and provisioning profile in the Unreal Editor and utilize the Apple ARKit plugin for the iOS exergame build. The communication between the desktop exergame and the mobile AR activities in order to start the AR mobile activities and make data exchanges (timings, successes, fails) is performed via a WiFi network. Finally, to extract data regarding the players' performance in the activities, a MySQL database is used.

In the supplementary materials section, additional resources are available regarding the exergames that have been developed.

3.2. Evaluation

An evaluation study was conducted in the facilities of an elderly care center with twenty-seven participants (N = 27) who were classified as end users (i.e., healthy older adults 65 years of age and older) and healthcare experts from the fields of physiotherapy, orthopedics, psychology, and physical education and sports science. Table 3 shows demographic information. The goal of the evaluation was to test the current version of the exergames and to assess their functionality and usability. Two phases of the evaluation were conducted. In the first phase, four (4) domain experts and eight (8) end users evaluated the exergames in a pre-pilot stage. In particular, the evaluation in this phase focused on the usability, tolerability, and applicability of the AR/VR exergames. The final prototype was then deployed to begin the pilot evaluation, which included fifteen (15) end users. Technology acceptance and other measures of feasibility were examined in this period.

Table 3. Characteristics of the participants (N = 27).

Characteristic	**Pre-Pilot Phase**		**Pilot Phase**
	End Users	**Experts**	**End Users**
N	8	4	15
Age (mean ± stdev)	71.3 ± 4.3	38.3 ± 4.9	67.5 ± 5.8
Gender (female/male)	6/2	2/2	10/5
Education years	9.4 ± 3.7	≥16	11.2 ± 3.4
Technology expertise *	1.8 ± 1.0	4	2.1 ± 1.3

* Technology expertise (e.g., use of computing devices and internet) was assessed with relevant questionnaire items on a scale of 0 to 4.

This study adhered to the standards of the Helsinki Declaration and received approval from the University of the Aegean's Ethical Research Committee (reference number 80322). Each participant signed a written informed consent form. To prevent any potential bias about the level of the intervention's acceptance, no compensation was given to the participants.

A research team member explained the goal of each exergame and how it worked before the exergame was evaluated. The participants were then engaged in playtesting after a brief demonstration of the game scenario. Qualified research assistants provided feedback and assistance whenever it was needed during the game. In the pre-pilot phase, the evaluation study required two days to complete, and eight hours were allocated for testing the exergames. The pilot phase aims to evaluate the final developed game platform in order to provide more sound evidence on the usefulness of the proposed exergames in relation to fall prevention. For all users, measurements of motor and cognitive functions are recorded before and after using the GAME2AWE platform to evaluate changes over time. Motor and cognitive functions can be measured using a variety of assessments and tests. In the context of this study, measures of motor function include the Choice Stepping Reaction Time (CSRT), Berg Balance Scale (BBS), Functional Reach Test (FRT), 30 Second Sit to Stand Test (30SST), and Time Up and Go (TUG). These assessments are designed to evaluate balance, gait, mobility, and other factors that can impact a person's risk of falling. Measures of cognitive function, on the other hand, include the Mini-Mental State Examination (MMSE) and the Montreal Cognitive Assessment (MoCA), both of which assess cognitive domains such as memory, attention, language, and orientation

The intervention team planned to use the GAME2AWE platform 2 times per week for 30 min until each participant completed 24 sessions. The majority of the games last 2 to 3 min, and there are usually brief rest intervals in between them. The pilot phase spans a period of 12 weeks and is currently in progress. The reported results in this paper are based on data collected until the fifth week of the pilot and focus on the perceived user experience and acceptance of the GAME2AWE platform. Measuring improvements in indicators of motor-cognitive function is out of the scope of this work. Representative photos from the evaluation study are shown in Figure 5.

(**a**) (**b**)

Figure 5. Representative photos from the evaluation study: (**a**) pre-pilot phase; (**b**) pilot phase.

3.2.1. Usability Assessment

Usability assessment was performed by collecting both qualitative and quantitative data. Short-term interviews and discussions with the seniors and the domain experts were carried out both in the pre-pilot and pilot phases to assess the usability of the exergames in order to establish whether such games could have a positive impact and to identify any features that must be implemented in the future. According to the interview with the seniors, 100% of the participants considered the exergames to be enjoyable, 90% said the movements were not difficult to learn, and 90% stated they would like to continue using the exergames after this study.

Positive feedback was given for the two game themes, the 3D graphics, and the smooth gameplay navigation. Positive feedback also indicated that users' confidence in the technology had grown as a result of their interaction with the GAME2AWE platform. The senior participants were pleased while playing the games, and throughout the duration of this study, there was a positive feeling and anticipation towards the planned activities, according to the feedback from the experts. A few responses from the participants after using the exergames:

"I really enjoyed playing the game, it was so much fun!"
"I felt like I was getting a workout while having a good time."
"The instructions were easy to follow, I had no trouble figuring out how to play."
"I liked that the game was tailored to my abilities, it didn't make me feel out of place."
"I would definitely recommend this game to my friends and family."
"I could see myself using this game regularly to stay active."
"I liked that the game had different levels of difficulty, it kept me challenged."
"The graphics and sound effects were great, it really immerses you in the game."
"I appreciate that the game is designed for older adults like me."
"I found the game easy to navigate and use, I had no trouble finding what I needed."

In the pre-pilot phase, perceived usability and usefulness were assessed using the System Usability Scale (SUS) questionnaire [52]. The questionnaire includes ten statements (Figure 6) with answers on a five-point scale from 1 (strongly disagree) to 5 (strongly agree). Half of the statements have a positive meaning (S1, S3, S5, S7, S9) and the other half have a negative meaning (S2, S4, S6, S8, S10). To compute the SUS score, the score contributions of each item should be added together. For items with positive meaning, the score contribution is calculated by subtracting 1 from the item's scale position. For items with negative meaning, the contribution is determined by subtracting the item's scale position from 5 [52]. The word "system" in the original questionnaire items was changed to the phrase "game platform" to better match the context of this study. According to best practices [53], the rating for each statement was adjusted so that the initial total scores on the 0–40 scale were transformed to the 0–100 scale. A score higher than 68 on the SUS scale denotes above-average usability [54].

ID	Statement
S1	I think that I would like to use this game platform frequently
S2	I found the game platform unnecessarily complex
S3	I thought the game platform was easy to use
S4	I think that I would need the support of a technical person to be able to use this game platform
S5	I found the various functions in this game platform were well integrated
S6	I thought there was too much inconsistency in this game platform
S7	I would imagine that most people would learn to use this game platform very quickly
S8	I found the game platform very cumbersome to use
S9	I felt very confident using the game platform
S10	I needed to learn a lot of things before I could get going with this game platform

Figure 6. SUS items with positive and negative statements alternated.

The SUS results for the GAME2AWE platform are depicted in Figure 7 as boxplots for the various participant categories. The average SUS score overall is 84.2 (SD = 10.1). Usability was rated more favorably and consistently by domain experts (mean SUS score 86.9 $\pm$ 3.1) than by end users (82.8 $\pm$ 12.3). Overall, the findings imply that all participants found the game platform to be highly acceptable. According to this evaluation, the objectives of the game tasks were comprehensible and sufficiently compelling to be pursued.

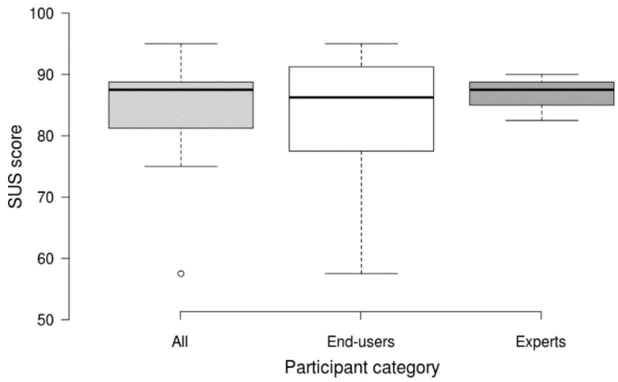

Figure 7. Perceived usability for each participant category as reflected by the SUS score.

Figure 8 depicts the distribution of the scores for each SUS statement and provides a more in-depth view of the evaluation that was provided by the end users. The elderly strongly believe that training on the game platform is characterized by ease of use, accessibility, and consistency, while the learning process is acceptable. This is justified by the responses in statements with negative connotations (S2, S6, S8, and S10), with values that fall in the lower portion of the scale found to be more intense. Nevertheless, the responses to the statement S4 (mean value 3.5 $\pm$ 1.5) reveal a realistic concern. Since this question assesses each participant's ability to operate the system independently, it is assumed that it may represent both the participants' overall lack of technological knowledge and the general belief that older individuals may have worries while using new technology. This could also explain why the average SUS score for end users is lower than that of experts.

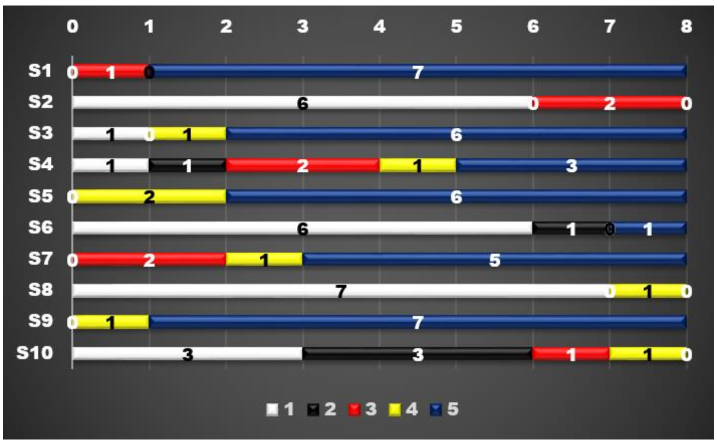

Figure 8. Analysis of end users' ratings on SUS questionnaire items.

3.2.2. Tolerability Assessment

The Virtual Reality Sickness Questionnaire (VRSQ) [55] was used to assess the tolerability of the participants in the VR-based training because simulator sickness is the most frequently reported adverse consequence when VR environments are used [56]. VRSQ is a self-report questionnaire that asks users to rate their level of agreement with various statements related to symptoms of VR sickness, such as nausea, dizziness, and headaches. The VRSQ typically includes items that assess symptoms such as eye strain, disorientation, and fatigue, as well as more general symptoms such as nausea and headache. A 4-point Likert scale is used to rate the severity of each symptom (i.e., 0 = none; 1 = slight; 2 = moderate; and 3 = severe). A total score is calculated by summing up the results of every item, and it is then converted to a percentage score. A higher score indicates that VR sickness is more severe. In order to uncover any other potentially negative effects, an open-ended question was also presented to the participants at the completion of the evaluation:

> *"Throughout and following the VR-based training, did you experience any uncomfortable symptoms?"*

Regarding uncomfortable symptoms, the majority of end users (63%) never had VR sickness symptoms. A mean VRSQ score of 2.92/100 (STDEV 4.03) in the end user group indicates that, overall, individuals who reported symptoms only experienced mild symptoms. The results of the VRSQ are depicted in Figure 9, and they reveal that there were a few instances of mild discomfort, with eye strain accounting for the largest number of occurrences.

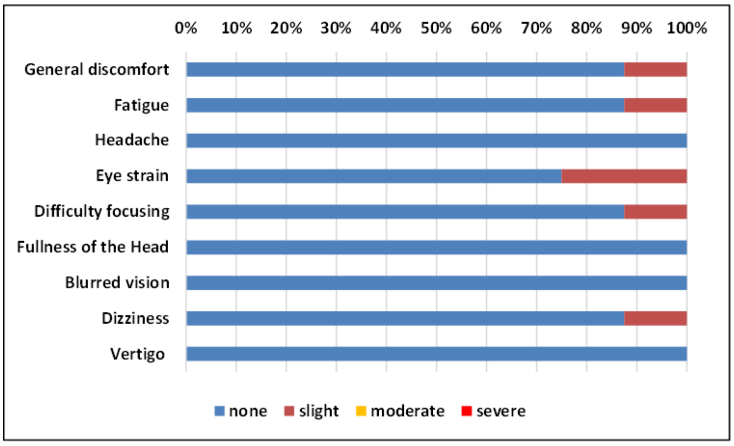

Figure 9. End user VRSQ results.

The low VRSQ score may be justified by the fact that the VR-based exergames have a limited range of motion, which reduces the likelihood of disorientation and nausea. Furthermore, the exergames use a first-person perspective, which allows users to feel more connected to the virtual environment and reduces the risk of VR sickness. The design choice made to use simple and intuitive controls, which enable users to focus on the game rather than the controls, also helps to reduce the risk of VR sickness. Overall, the clear goal and objective of each exergame help users to stay engaged and focused, which also lowers the chance of experiencing VR sickness.

3.2.3. Applicability Assessment

After testing each exergame, its applicability was evaluated through a discussion with the domain experts. The interview focused on the suitability of the exergames for motor and cognitive training to reduce the risk of elderly people falling, and questions included the appropriateness of the exercises, the effectiveness and safety of the movements, the suitability of the difficulty levels, and the degree to which the movements are incorporated well into gameplay. Positive comments indicated that the exercises included in the exergames were safe to execute, might enhance postural control, and help seniors maintain their strength and balance, and therefore decrease frailties and fall risk. Additionally, an important assertion was that such exergames could provide an enjoyable and engaging way for the elderly to exercise, which may increase adherence to a regular exercise program. Since a participatory design approach was used to create the games with a focus on maximizing their usability and applicability [47], this feedback was a kind of validation of the appropriateness of the gameplay structure.

Additionally, each senior participant received a quick interview to gather qualitative information. The review of the collected data and the improvised comments showed that the incentive to exercise was quite high because all of the participants stated they enjoyed using the exergames, they acknowledged that the game platform had a reliable operation, and they expressed an aspiration to keep using it.

Some suggestions made for improvement include the addition of new movements recommended by the physician, a wider range of game content, and more difficulty levels, as more capable seniors found the effort required to complete some game activities to be rather simple. Other suggestions that could improve the platform in the long term refer to incorporating social and multiplayer features that allow for interaction and competition with others, which can increase engagement and motivation, and incorporating additional sensors and other assistive technologies to enable more accurate and real-time feedback.

3.2.4. Technology Acceptance Assessment

A questionnaire was given to the participants of the pilot study in order to determine the technology acceptance of the exergame platform. The constructs of the Unified Theory of Acceptance and Use of Technology (UTAUT) model [57], outlined in Figure 10, served as the foundation for this questionnaire. UTAUT has been extensively used as a framework for understanding how different factors influence the acceptance and use of technology by the elderly population [58].

Construct	Description
Performance Expectancy (PE)	The degree to which the individuals believe that the use of the technology will result in performance gains.
Effort Expectancy (EE)	The ease of use of the technology.
Social Influence (SI)	The extent to which individuals perceive that important others (e.g., family and friends) believe they should use the technology.
Facilitating Conditions (FC)	The perceived extent to which the organizational and technical infrastructure required for the support of the technology usage exist.
Behavioral Intention (BI)	The degree to which the individuals have the intention to use the technology in the future.

Figure 10. UTAUT constructs adopted in this study.

The UTAUT model combines eight previously developed models into a single, inclusive model, which proposes that four main factors influence the acceptance and use of technology: performance expectancy (PE), effort expectancy (EE), social influence (SI), and facilitating conditions (FC). These components have an impact on behavioral intention (BI) under the influence of moderating variables, including age, gender, experience, and voluntarism, which result in use behavior.

PE refers to the belief that using the technology will lead to improved performance in a specific task or activity. For exergames, this would include the belief that playing the game will lead to improved physical function and health. EE refers to the belief that using the technology will be easy and require minimal effort. For exergames, this would include the belief that the game is easy to use and understand, and that it does not require a lot of technical knowledge or skill. SI refers to the influence of others on the individual's decision to use the technology. For exergames, this would include the influence of family and friends, as well as healthcare professionals, on the individual's decision to use the game. FC refers to the resources and support that are available to help individuals use the technology. For exergames, this would include the availability of equipment and technical support, as well as the availability of training and instructions on how to use the game.

The UTAUT model proposes that BI is a key mediator that influences actual behavior. BI refers to an individual's intention to engage in a specific behavior, such as using a technology. According to the UTAUT model, BI is influenced by the four main factors mentioned above, which are related to the prediction of behavioral intention to use technology. For example, if the older adult believes that playing exergames will lead to improved physical function and health, this will have a positive influence on their attitude towards the technology and their behavioral intention to use it. BI, in turn, has a direct effect on actual behavior. For example, if an older adult has a strong BI to use exergames, it is more likely that they will actually engage in the behavior and use the technology.

Participants were asked to rate their subjective opinions of PE, EE, SI, FC, and BI on a 5-point scale using the UTAUT questionnaire adapted for exergaming specificity in this study (Table 4).

Table 4. UTAUT-based questionnaire for GAME2AWE exergames acceptance assessment.

Construct	Item Code	Item
Performance Expectancy	PE1	I find the exergames useful in my daily life.
	PE2	Using the exergames increases my chances of improving my health.
	PE3	Using the exergames helps me in improving my mood.
	PE4	Using the exergames increases my self-confidence.
Effort Expectancy	EE1	Learning how to use the exergames is easy for me.
	EE2	My interaction with the exergames is clear and understandable.
	EE3	I find the exergames easy to use.
	EE4	It is easy for me to become skillful at using the exergames.
Social Influence	SI1	People who are important to me think that I should use the exergames.
	SI2	People who influence my behavior think that I should use the exergames.
	SI3	People whose opinions that I value prefer that I use the exergames.
Facilitating Conditions	FC1	I have the resources necessary to use the exergames.
	FC2	I have the knowledge necessary to use the exergames.
	FC3	I can get help from others when I have difficulties using the exergames
Behavioral Intention	BI1	I intend to continue using the exergames in the future.
	BI2	I predict I will use the exergames in my life.
	BI3	I plan to continue to use the exergames frequently.

Table 5 gives the descriptive statistics of the responses collected as well as the Cronbach's alpha score for each individual construct in the UTAUT model employed. The questionnaire used can be considered reliable, and thus, the results are valid, given that the alpha score is above 0.7 for all constructs [59]. The descriptive statistics show that the participants have a positive attitude towards the exergames. In particular, regarding the PE construct, the majority of seniors believe that the exergames will help them improve their physical condition. Furthermore, data from the EE category indicate that seniors regard the system to be user-friendly. Regarding SI, the mean score shows that family and friends encourage the elderly to use the exergames. The score for FC is also high on the scale, indicating that the resources and support needed to use the exergames are readily available and accessible. The BI score is 4.042 ± 0.751, indicating that participants show a strong desire and intention to use the exergames. Overall, considering the BI score in conjunction with the other factors that might affect the actual behavior provide evidence that the participants highly accept the exergame platform.

Table 5. Descriptive statistics and Cronbach's alpha score for individual constructs in the UTAUT model (N = 15).

Construct	Cronbach's Alpha	Mean (M)	Std. Deviation (SD)
PE	0.826	4.125	0.900
EE	0.769	4.000	0.834
SI	0.737	3.875	0.850
FC	0.830	3.958	0.859
BI	0.740	4.042	0.751

A Spearman's correlation analysis was applied to determine which constructs are the most influential in terms of using the GAME2AWE exergames, as the dataset was not satisfied with the normality test and had outliers. According to the analysis (Figure 11, Table 6), PE and BI have the strongest significant positive relationship (0.825 at the 0.01 level), followed by FC and EE (0.612 and 0.555 at the 0.01 level). The SI was found to be insignificantly correlated in terms of predicting the behavioral intention of the use of the exergames. Overall, the results support our qualitative findings by showing that the proposed exergames will have a positive effect on the elderly exercising.

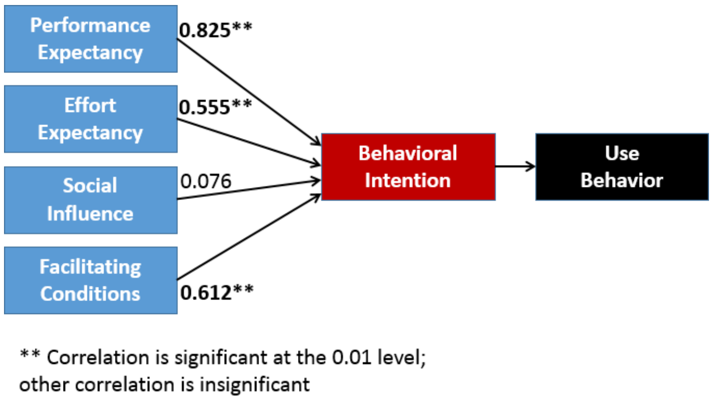

Figure 11. The UTAUT research model with Spearman's Rho correlations.

Table 6. Correlation matrix of UTAUT constructs (N = 15).

Construct	PE	EE	SI	FC	BI
PE	1.000				
EE	**0.461** *	1.000			
SI	0.126	**0.664** **	1.000		
FC	**0.508** *	**0.971** **	**0.631** **	1.000	
BI	**0.825** **	**0.555** **	0.076	**0.612** **	1.000

Bold font indicates statistically significant correlation. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

The analysis shows that PE plays the most important role in terms of intent to use. As a result, the elderly realized that by using the GAME2AWE exergames, their motor and cognitive skills would improve, enhancing their abilities in day-to-day activities and reducing their fear of falling. In the context of the pilot study, the elderly considered that the FC factor (i.e., resources, user-friendly instructions, and encouraging assistance) constitutes a critical construct to use the exergames. The participants value the EF aspect of the GAME2AWE platform as well, as this construct ranks as the third most significant factor in this study. The effects of SI on BI are typically regulated by individual traits such as various combinations of gender, age, and experiences [57]. However, in this study, SI was not found to be statistically connected with the future intention to utilize the exergames.

Table 6 gives the interrelationship between the critical constructs examined in the pilot study that influence future intent to use the GAME2AWE platform. PE is moderately correlated with FC and EE (0.508 and 0.461 at the 0.05 level); however, it is not correlated with the SI in this study. EE has a very strong positive correlation with the FC of the exergame platform (0.971 at the 0.01 level), and is also moderately positively correlated with SI (0.664 at the 0.01 level). Finally, SI is positively correlated with FC (0.631 at the 0.01 level). This suggests that the exergame-based solution, i.e., the GAME2AWE platform, will have a positive impact on elderly motor-cognitive training, thus validating the qualitative findings.

4. Discussion

The GAME2AWE platform was developed to integrate motor and cognitive exercises via AR/VR technology for the promotion of elderly health. A key topic investigated in this work was whether older people would accept this new exergame platform. Since it was unknown how the elderly would have responded to the usage of new technologies, it was projected that the participants' levels of acceptance of the GAME2AWE platform might differ. A technology acceptance study was performed along with a qualitative analysis in order to provide insights into the factors that influence the behavioral intention to use such exergaming technology. In that respect, this work contributes to the research on elderly exergames toward motor-cognitive training.

This work emphasizes the importance of developing exergames specifically designed for seniors. This study employed validated models such as UTAUT, inferential statistics, and qualitative analysis to investigate the acceptance level of the game platform by the targeted users. Exergaming, according to the elderly and expert feedback, could keep the seniors active and improve their physical and cognitive condition. The study performed suggests that in the context of elderly daily care centers, exergames may be an effective approach to encourage the elderly to exercise. According to the findings of the pilot study, the targeted population is eager to embrace and use AR/VR technologies. This is attested by the high mean BI score in the UTAUT model, reflecting the intention to use the developed exergames by the elderly. As a result, the elderly accepted AR/VR exergaming for physical and cognitive training that was specifically designed for seniors.

According to the statistical findings (Figure 11, Table 6), PE, FC, and EE are the factors that will most likely influence exergame usage by the elderly in the future. This shows that the GAME2AWE exergame platform is motivating seniors to exercise. The results of the descriptive statistics demonstrate also that friends and family are also very supportive of the elderly utilizing exergames, as evidenced by the fair SI mean value. Despite the fact that the literature has demonstrated that SI is a key concept in the intention of utilizing a new technology [60], no such evidence has been found in this study. In this work, it was discovered that SI did not significantly correlate with the other factors or the intention to use such technology in the future. This might be the case because the elderly experience themselves that playing exergames is quite enjoyable and helps them improve their physical condition.

Age, gender, and experience are moderating variables that affect how people intend to use new technology [57]. The age of participants in this study is restricted to 65 years and older, and none of the subjects had ever used AR/VR exergames. Both elderly females and males indicated a positive attitude towards using the GAME2AWE platform in the future. A marginally greater mean BI to use exergames in the future was seen in the senior females (4.063 ± 0.772) versus males (4.000 ± 0.756). It is hypothesized that because the exergames were specifically designed for seniors, their development process integrated knowledge gained through close examination of how senior men and women should interact with such exergames.

In this study, it was determined whether seniors could embrace a new exergame platform. Furthermore, the critical factors affecting future use were identified, and their interrelation was outlined. Future research can complement this work by exploring additional topics, such as how one construct influences another. Likewise, a broader study can be performed that will take into account the influence of age variation in the UTAUT model. Future research may also examine the impact that the experience in various exergame usage levels may have on the elderly intention to use the technology in the future. Finally, this study found that participants of both genders are almost to the same extent positive about using the GAME2AWE platform in the future. However, the effect of gender on exergame acceptance and its relationship to other factors (i.e., age, physical fitness, previous experience with gaming or exergaming, socio-economic status, cultural background, individual preferences and attitudes towards technology, etc.) has not been studied. In addition, factors related to the design and characteristics of the exergame platform, such as the level of interactivity and game difficulty, may also have a differential impact on gender acceptance. These potential confounding factors can be investigated further in a future study.

VR sickness is a common phenomenon experienced by some people when using VR technology. The majority of end users (63%) did not experience VR sickness symptoms, and those who did reported only mild symptoms, with eye strain being the most common. The limited range of motion, first-person perspective, simple controls, short duration, and clear objectives in the VR exergames may have contributed to the low likelihood of VR sickness. In general, one of the main factors that can contribute to VR sickness is the vergence accommodation conflict (VAC) [61]. This occurs when there is a mismatch between the distance at which a person's eyes converge (the point at which the eyes turn inward to focus on an object) and the distance at which their eyes accommodate (the point at which the lens in the eye changes shape to focus on an object) [62]. Modern VR technologies, such as the Oculus Quest 2 used in this study, address VAC through the use of high-resolution displays and a high refresh rate. This can help to reduce the severity of VAC by providing a more detailed and fluid image, reducing the discrepancy between the distance at which the eyes converge and the distance at which they accommodate. The Oculus Quest 2 features an interpupillary distance adjustment mechanism that enables users to modify the distance between the lenses to correspond to their individual eye spacing. Moreover, the implementation of varifocal displays and eye-tracking technology are recognized as some of the most effective strategies for managing the challenge of VAC in VR settings [63].

Conclusively, the following suggestions are provided for exergame developers based on the results of our study, especially for AR/VR exergames that are more acceptable to older individuals. Developers of such exergames should ensure that a game is sufficient to provide health benefits to older adults, and highlight what benefits the players could obtain and how effectively the game could provide these benefits to the targeted users. This is because perceived usefulness had the strongest effect on older adults' intention towards using AR/VR exergames. In addition, easy-to-use movements such as walking on the spot, rowing, and stepping forwards, backward, and sideways should be employed when creating AR/VR exergames. The intention of older persons to adopt AR/VR exergames is positively predicted by the ease of use factor. Furthermore, since the game merely employs simple, easy-to-understand, and intuitive motions, no further assistance should be required. AR/VR exergame developers should offer a variety of in-game achievements to promote continued engagement. Using points, leaderboards, or a badge system are some of the ways to achieve this [64]. Exergames should offer varying degrees of challenge to keep players engaged and motivated. Users will be able to test their abilities using that challenge and attempt to improve. Additionally, progressing to a harder level will give users the impression that they accomplished something and that the game is actually helping them. Finally, since many participants have shown an interest in playing with other players, AR/VR exergames should support social interaction within the games and motivate older adults to participate in groups. According to studies, social interaction could encourage older persons to share advice for improved performance, which might increase their interest in a game [18].

5. Conclusions

One of the main goals of the GAME2AWE platform discussed in this work is to provide AR/VR exergames for fall prevention in older adults. The games developed require the player to perform movements that mimic real-life activities, such as walking or stepping, which can help improve awareness of body position and muscle strength. These improvements in balance and coordination can decrease the risk of falls. Nevertheless, the games require a certain level of cognitive processing, such as decision making, reaction time, and attention, which can contribute to cognitive stimulation and improvement. Additionally, the AR/VR exergames developed can increase motivation to exercise among older adults. Many older adults may find traditional exercise routines to be boring or uninteresting, but the immersive and interactive nature of AR/VR exergames can make exercise more enjoyable and engaging. This can help increase adherence to exercise regimens and make it more likely that older adults will stick with an exercise program long-term. The latter requires longitudinal studies to track the exercise behaviors of older adults over an extended period of time, measuring adherence and outcomes such as changes in physical function, cognitive performance, and overall well-being.

The present study examined the feasibility and acceptability of the GAME2AWE platform, which offers exergames tailored specifically for the elderly population. The interim results of the pilot study offer compelling evidence regarding the platform's acceptability and factors influencing future usage of exergames. This study employed validated models such as UTAUT and qualitative analysis to assess the level of acceptance of the game platform by elderly users. Feedback from both the elderly and experts in the field suggests that exergaming can promote physical and mental activity among the elderly. This study's findings indicate that exergames may serve as an effective approach to encourage elderly individuals to engage in physical exercise, particularly in daily care centers. The elderly population is receptive to the use of AR/VR technologies and displays an eagerness to engage with the developed exergames. We anticipate measuring positive improvements in motor and cognitive functions at the end of the pilot evaluation study.

Supplementary Materials: A number of demo videos of exergames included in the GAME2AWE platform can be found on the project's YouTube channel: https://www.youtube.com/channel/UCnj5jG-3grlLTyTHN8zuyCQ (accessed on 29 January 2023).

Author Contributions: Conceptualization, C.G.; methodology, C.G.; software, E.D.; validation, C.G., E.D. and D.G.; investigation, C.G. and E.D.; resources, D.G.; data curation, C.G.; writing—original draft preparation, C.G.; writing—review and editing, C.G., E.D. and D.G.; visualization, C.G.; supervision, C.G.; project administration, C.G.; funding acquisition, C.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship, and Innovation, under the call RESEARCH-CREATE-INNOVATE (project code: T2EDK-04785).

Data Availability Statement: Data is available upon reasonable request to the corresponding author.

Acknowledgments: We would like to thank our colleagues in the GAME2AWE project for their support in the development of the game platform, all the elderly adults, and the healthcare experts who participated in this study. We are grateful to Giannis Matsoukas for his support in the pilot study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tanaka, K.; Parker, J.; Baradoy, G.; Sheehan, D.; Holash, J.R.; Katz, L. A Comparison of Exergaming Interfaces for Use in Rehabilitation Programs and Research. *Loading* **2012**, *6*, 9.
2. Gallou-Guyot, M.; Mandigout, S.; Bherer, L.; Perrochon, A. Effects of Exergames and Cognitive-Motor Dual-Task Training on Cognitive, Physical and Dual-Task Functions in Cognitively Healthy Older Adults: An Overview. *Ageing Res. Rev.* **2020**, *63*, 101135. [CrossRef]
3. Thomas, E.; Battaglia, G.; Patti, A.; Brusa, J.; Leonardi, V.; Palma, A.; Bellafiore, M. Physical Activity Programs for Balance and Fall Prevention in Elderly: A Systematic Review. *Medicine* **2019**, *98*, e16218. [CrossRef]
4. Choi, S.D.; Guo, L.; Kang, D.; Xiong, S. Exergame Technology and Interactive Interventions for Elderly Fall Prevention: A Systematic Literature Review. *Appl. Ergon.* **2017**, *65*, 570–581. [CrossRef] [PubMed]
5. Ambrose, A.F.; Paul, G.; Hausdorff, J.M. Risk Factors for Falls among Older Adults: A Review of the Literature. *Maturitas* **2013**, *75*, 51–61. [CrossRef] [PubMed]
6. Kaplan, A.D.; Cruit, J.; Endsley, M.; Beers, S.M.; Sawyer, B.D.; Hancock, P.A. The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis. *Hum. Factors* **2021**, *63*, 706–726. [CrossRef] [PubMed]
7. Dermody, G.; Whitehead, L.; Wilson, G.; Glass, C. The Role of Virtual Reality in Improving Health Outcomes for Community-Dwelling Older Adults: Systematic Review. *J. Med. Internet. Res.* **2020**, *22*, e17331. [CrossRef] [PubMed]
8. Liu, M.; Zhou, K.; Chen, Y.; Zhou, L.; Dapeng, B.; Zhou, J. Is virtual reality training more effective than traditional physical training on balance and functional mobility in healthy older adults? A systematic review and meta-analysis. *Front. Hum. Neurosci.* **2022**, *125*, 843481. [CrossRef]
9. Yu, D.; Li, X.; Lai, F.H. The Effect of Virtual Reality on Executive Function in Older Adults with Mild Cognitive Impairment: A Systematic Review and Meta-Analysis. *Aging Ment. Health* **2022**, 1–11. [CrossRef]
10. Chen, Y.-F.; Janicki, S. A Cognitive-Based Board Game with Augmented Reality for Older Adults: Development and Usability Study. *JMIR Serious Games* **2020**, *8*, e22007. [CrossRef]
11. Afifi, T.; Collins, N.; Rand, K.; Otmar, C.; Mazur, A.; Dunbar, N.E.; Fujiwara, K.; Harrison, K.; Logsdon, R. Using Virtual Reality to Improve the Quality of Life of Older Adults with Cognitive Impairments and Their Family Members Who Live at a Distance. *Health Commun.* **2022**, 1–12. [CrossRef] [PubMed]

12. Bauer, A.C.M.; Andringa, G. The Potential of Immersive Virtual Reality for Cognitive Training in Elderly. *Gerontology* **2020**, *66*, 614–623. [CrossRef] [PubMed]
13. López-Nava, I.H.; Rodriguez, M.D.; García-Vázquez, J.P.; Perez-Sanpablo, A.I.; Quiñones-Urióstegui, I.; Meneses-Peñaloza, A.; Castillo, V.; Cuaya-Simbro, G.; Armenta, J.S.; Martínez, A.; et al. Current State and Trends of the Research in Exergames for the Elderly and Their Impact on Health Outcomes: A Scoping Review. *J. Ambient. Intell. Human. Comput.* 2022. [CrossRef]
14. Piech, J.; Czernicki, K. Virtual Reality Rehabilitation and Exergames—Physical and Psychological Impact on Fall Prevention among the Elderly—A Literature Review. *Appl. Sci.* **2021**, *11*, 4098. [CrossRef]
15. Høeg, E.R.; Povlsen, T.M.; Bruun-Pedersen, J.R.; Lange, B.; Nilsson, N.C.; Haugaard, K.B.; Faber, S.M.; Hansen, S.W.; Kimby, C.K.; Serafin, S. System Immersion in Virtual Reality-Based Rehabilitation of Motor Function in Older Adults: A Systematic Review and Meta-Analysis. *Front. Virtual Real.* **2021**, *2*, 647993. [CrossRef]
16. Seifert, A.; Schlomann, A. The use of virtual and augmented reality by older adults: Potentials and challenges. *Front. Virtual Real.* **2021**, *2*, 639718. [CrossRef]
17. Brox, E.; Konstantinidis, S.T.; Evertsen, G. User-Centered Design of Serious Games for Older Adults Following 3 Years of Experience with Exergames for Seniors: A Study Design. *JMIR Serious Games* **2017**, *5*, e2. [CrossRef]
18. Li, J.; Xu, X.; Pham, T.P.; Theng, Y.-L.; Katajapuu, N.; Luimula, M. Exergames Designed for Older Adults: A Pilot Evaluation on Psychosocial Well-Being. *Games Health J.* **2017**, *6*, 371–378. [CrossRef]
19. Bacha, J.M.R.; Gomes, G.C.V.; de Freitas, T.B.; Viveiro, L.A.P.; da Silva, K.G.; Bueno, G.C.; Varise, E.M.; Torriani-Pasin, C.; Alonso, A.C.; Luna, N.M.S.; et al. Effects of kinect adventures games versus conventional physical therapy on postural control in elderly people: A randomized controlled trial. *Games Health J.* **2018**, *7*, 24–36. [CrossRef]
20. Baranowski, T.; Lyons, E.J. Scoping Review of Pokémon Go: Comprehensive Assessment of Augmented Reality for Physical Activity Change. *Games Health J.* **2020**, *9*, 71–84. [CrossRef]
21. Winter, D.A. Human balance and posture control during standing and walking. *Gait Posture* **1995**, *3*, 193–214. [CrossRef]
22. Cuevas-Trisan, R. Balance problems and fall risks in the elderly. *Clin. Geriatr. Med.* **2019**, *35*, 173–183. [CrossRef]
23. Kannus, P.; Niemi, S.; Palvanen, M.; Parkkari, J. Rising incidence of fall-induced injuries among elderly adults. *J. Public Health* **2005**, *13*, 212–215. [CrossRef]
24. Heinrich, S.; Rapp, K.; Rissmann, U.; Becker, C.; König, H.H. Cost of falls in old age: A systematic review. *Osteoporos. Int.* **2010**, *21*, 891–902. [CrossRef] [PubMed]
25. Muir, S.W.; Berg, K.; Chesworth, B.; Klar, N.; Speechley, M. Quantifying the magnitude of risk for balance impairment on falls in community-dwelling older adults: A systematic review and meta-analysis. *J. Clin. Epidemiol.* **2010**, *63*, 389–406. [CrossRef]
26. Robinovitch, S.N.; Feldman, F.; Yang, Y.; Schonnop, R.; Leung, P.M.; Sarraf, T.; Sims-Gould, J.; Loughin, M. Video capture of the circumstances of falls in elderly people residing in long-term care: An observational study. *Lancet* **2013**, *381*, 47–54. [CrossRef]
27. Gillespie, L.D.; Robertson, M.C.; Gillespie, W.J.; Sherrington, C.; Gates, S.; Clemson, L.; Lamb, S.E. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst. Rev.* **2012**, *9*, CD007146. [CrossRef]
28. Sherrington, C.; Whitney, J.C.; Lord, S.R.; Herbert, R.D.; Cumming, R.G.; Close, J.C. Effective exercise for the prevention of falls: A systematic review and meta-analysis. *J. Am. Geriatr. Soc.* **2008**, *56*, 2234–2243. [CrossRef] [PubMed]
29. World Health Organization. *WHO Global Report on Falls Prevention in Older Age*; World Health Organization: Geneva, Switzerland, 2008; ISBN 978-92-4-156353-6.
30. El-Khoury, F.; Cassou, B.; Charles, M.A.; Dargent-Molina, P. The effect of fall prevention exercise programmes on fall induced injuries in community dwelling older adults: Systematic review and meta-analysis of randomised controlled trials. *BMJ* **2013**, *347*, f6234. [CrossRef] [PubMed]
31. Schoene, D.; Lord, S.R.; Delbaere, K.; Severino, C.; Davies, T.A.; Smith, S.T. A randomized controlled pilot study of home-based step training in older people using videogame technology. *PLoS ONE* **2013**, *8*, e57734. [CrossRef]
32. Pacheco, T.B.F.; de Medeiros, C.S.P.; de Oliveira, V.H.B.; Vieira, E.R.; de Cavalcanti, F.A.C. Effectiveness of exergames for improving mobility and balance in older adults: A systematic review and meta-analysis. *Syst. Rev.* **2020**, *9*, 163. [CrossRef]
33. Iakovidis, P.; Lytras, D.; Fetlis, A.; Kasimis, K.; Ntinou, S.R.; Chatzikonstantinou, P. The efficacy of exergames on balance and reducing falls in older adults: A narrative review. *Int. J. Orthop.* **2023**, *9*, 221–225. [CrossRef]
34. Zhao, Y.; Feng, H.; Wu, X.; Du, Y.; Yang, X.; Hu, M.; Ning, H.; Liao, L.; Chen, H.; Zhao, Y. Effectiveness of exergaming in improving cognitive and physical function in people with mild cognitive impairment or dementia: Systematic review. *JMIR Serious Games* **2020**, *8*, e16841. [CrossRef] [PubMed]
35. Chen, M.; Tang, Q.; Xu, S.; Leng, P.; Pan, Z. Design and Evaluation of an Augmented Reality-Based Exergame System to Reduce Fall Risk in the Elderly. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7208. [CrossRef] [PubMed]
36. Stamm, O.; Vorwerg, S.; Müller-Werdan, U. Exergames in Augmented Reality for Older Adults with Hypertension: A Qualitative Study Exploring User Requirements. In *International Conference on Human-Computer Interaction*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 232–244. [CrossRef]
37. Nishchyk, A.; Geentjens, W.; Medina, A.; Klein, M.; Chen, W. An Augmented Reality Game for Helping Elderly to Perform Physical Exercises at Home. In *International Conference on Computers Helping People with Special Needs*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 233–241. [CrossRef]

38. Pereira, G.A.F.; Bacha, J.M.R.; Silva, I.B.A.N.; Pompeu, J.E.; de Deus Lopes, R. Virtual Reality and Augmented Reality Exergames for Older Fallers: Considerations about Design and Applicability by Physical Therapists. In *Anais Estendidos do XX Simpósio Brasileiro de Jogos e Entretenimento Digital*; SBC: Brasilia, Brazil, 2021; pp. 855–862. [CrossRef]
39. Muñoz, J.; Mehrabi, S.; Li, Y.; Basharat, A.; Middleton, L.E.; Cao, S.; Barnett-Cowan, M.; Boger, J. Immersive Virtual Reality Exergames for Persons Living with Dementia: User-Centered Design Study as a Multistakeholder Team during the COVID-19 Pandemic. *JMIR Serious Games* **2022**, *10*, e29987. [CrossRef] [PubMed]
40. Trombetta, M.; Henrique, P.P.B.; Brum, M.R.; Colussi, E.L.; De Marchi, A.C.B.; Rieder, R. Motion Rehab AVE 3D: A VR-Based Exergame for Post-Stroke Rehabilitation. *Comput. Methods Programs Biomed.* **2017**, *151*, 15–20. [CrossRef]
41. Kwan, R.Y.C.; Liu, J.Y.W.; Fong, K.N.K.; Qin, J.; Leung, P.K.-Y.; Sin, O.S.K.; Hon, P.Y.; Suen, L.W.; Tse, M.-K.; Lai, C.K. Feasibility and Effects of Virtual Reality Motor-Cognitive Training in Community-Dwelling Older People with Cognitive Frailty: Pilot Randomized Controlled Trial. *JMIR Serious Games* **2021**, *9*, e28400. [CrossRef] [PubMed]
42. Xu, W.; Liang, H.-N.; Yu, K.; Wen, S.; Baghaei, N.; Tu, H. Acceptance of Virtual Reality Exergames among Chinese Older Adults. *Int. J. Hum.–Comput. Interact.* **2022**, *39*, 1134–1148. [CrossRef]
43. Goumopoulos, C.; Drakakis, E.; Gklavakis, D. Augmented and Virtual Reality Based Exergames in GAME2AWE for Elderly Fall Prevention. In Proceedings of the 2022 18th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Thessaloniki, Greece, 10 October 2022; pp. 100–105. [CrossRef]
44. Danousis, M.; Goumopoulos, C.; Fakis, A. Exergames in the GAME2AWE Platform with Dynamic Difficulty Adjustment. In Proceedings of the Entertainment Computing–ICEC 2022: 21st IFIP TC 14 International Conference, ICEC 2022, Bremen, Germany, 1–3 November 2022; pp. 214–223. [CrossRef]
45. Sanders, E.B.N. From User-Centered to Participatory Design Approaches. In *Design and the Social Sciences*; Frascara, J., Ed.; CRC Press: Boca Raton, FL, USA, 2002; pp. 18–25. ISBN 978-0-429-21927-6.
46. Chartomatsidis, M.; Goumopoulos, C. Development and Evaluation of a Motion-Based Exercise Game for Balance Improvement. In Proceedings of the Information and Communication Technologies for Aging Well and e-Health: 5th International Conference, ICT4AWE 2019, Heraklion, Crete, Greece, 2–4 May 2019; Revised Selected Papers 5. pp. 119–141. [CrossRef]
47. Goumopoulos, C.; Chartomatsidis, M.; Koumanakos, G. Participatory Design of Fall Prevention Exergames Using Multiple Enabling Technologies. In *ICT4AWE*; SciTePress: Setubal, Portugal, 2022; pp. 70–80. [CrossRef]
48. Tahmosybayat, R.; Baker, K.; Godfrey, A.; Caplan, N.; Barry, G. Movements of Older Adults during Exergaming Interventions That Are Associated with the Systems Framework for Postural Control: A Systematic Review. *Maturitas* **2018**, *111*, 90–99. [CrossRef]
49. Goumopoulos, C.; Ougkrenidis, D.; Gklavakis, D.; Ioannidis, I. A Smart Floor Device of an Exergame Platform for Elderly Fall Prevention. In Proceedings of the 2022 25th Euromicro Conference on Digital System Design (DSD), Maspalomas, Spain, 31 August–2 September 2022; pp. 585–592. [CrossRef]
50. Cohavi, O.; Levy-Tzedek, S. Young and old users prefer immersive virtual reality over a social robot for short-term cognitive training. *Int. J. Hum.–Comput. Stud.* **2022**, *161*, 102775. [CrossRef]
51. Lord, S.R.; Fitzpatrick, R.C. Choice Stepping Reaction Time: A Composite Measure of Falls Risk in Older People. *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* **2001**, *56*, M627–M632. [CrossRef]
52. Brooke, J. SUS-A Quick and Dirty Usability Scale. *Usability Eval. Ind.* **1996**, *189*, 4–7. [CrossRef]
53. Sauro, J. *A Practical Guide to the System Usability Scale: Background, Benchmarks & Best Practices*; Measuring Usability LLC: Denver, CO, USA, 2011.
54. Bangor, A.; Kortum, P.T.; Miller, J.T. An empirical evaluation of the system usability scale. *Intl. J. Hum.–Comput. Interact.* **2008**, *24*, 574–594. [CrossRef]
55. Kim, H.K.; Park, J.; Choi, Y.; Choe, M. Virtual Reality Sickness Questionnaire (VRSQ): Motion Sickness Measurement Index in a Virtual Reality Environment. *Appl. Ergon.* **2018**, *69*, 66–73. [CrossRef] [PubMed]
56. Grassini, S.; Laumann, K.; Luzi, A.K. Association of Individual Factors with Simulator Sickness and Sense of Presence in Virtual Reality Mediated by Head-Mounted Displays (HMDs). *Multimodal Technol. Interact.* **2021**, *5*, 7. [CrossRef]
57. Venkatesh, V.; Morris, M.G.; Davis, G.B.; Davis, F.D. User Acceptance of Information Technology: Toward a Unified View. *MIS Q.* **2003**, *27*, 425. [CrossRef]
58. Yap, Y.-Y.; Tan, S.-H.; Choon, S.-W. Elderly's Intention to Use Technologies: A Systematic Literature Review. *Heliyon* **2022**, *8*, e08765. [CrossRef] [PubMed]
59. Hair, J.F., Jr.; Hult, G.T.M.; Ringle, C.M.; Sarstedt, M. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*; Sage Publications: Newbury Park, CA, USA, 2021.
60. de Veer, A.J.E.; Peeters, J.M.; Brabers, A.E.; Schellevis, F.G.; Rademakers, J.J.J.; Francke, A.L. Determinants of the Intention to Use E-Health by Community Dwelling Older People. *BMC Health Serv. Res.* **2015**, *15*, 103. [CrossRef] [PubMed]
61. Hsiang, E.L.; Yang, Z.; Yang, Q.; Lai, P.C.; Lin, C.L.; Wu, S.T. AR/VR light engines: Perspectives and challenges. *Adv. Opt. Photonics* **2022**, *14*, 783–861. [CrossRef]
62. Yin, K.; Hsiang, E.L.; Zou, J.; Li, Y.; Yang, Z.; Yang, Q.; Lai, P.C.; Lin, C.L.; Wu, S.T. Advanced liquid crystal devices for augmented reality and virtual reality displays: Principles and applications. *Light Sci. Appl.* **2022**, *11*, 161. [CrossRef]

63. Kramida, G. Resolving the vergence-accommodation conflict in head-mounted displays. *IEEE Trans. Vis. Comput. Graph.* **2015**, *22*, 1912–1931. [CrossRef] [PubMed]
64. Fu, Y.; Hu, Y.; Sundstedt, V. A Systematic Literature Review of Virtual, Augmented, and Mixed Reality Game Applications in Healthcare. *ACM Trans. Comput. Healthc.* **2022**, *3*, 1–27. [CrossRef]