Augmented and Virtual Reality Based Exergames in GAME2AWE for Elderly Fall Prevention

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***Abstract*— The GAME2AWE platform aims to provide a versatile tool for elderly fall prevention through exergames that integrate aerobic, strength-enhancing and balance-enhancing exercises. In addition, cognitive improvements are expected due to dual task training activities. In this context, the use of augmented reality (AR) and virtual reality (VR) to build such exergames is investigated through a review of relevant literature and an evaluation study of a functional prototype of the GAME2AWE platform. Fall prevention exercises have been integrated into two scenario-based exergame themes, "Life on a Farm" and "Fun Park Tour", to be able to assess their applicability on the targeted users based on healthcare experts' evaluation. Test and evaluation sessions were conducted with eight end-users and four experts. The results indicate a positive assessment by the research sample in terms of usability, tolerability, and applicability. Feedback from user testing will be used for the final development stage which will fuel a pilot trial to assess the effects of AR and VR-based motor-cognitive training in community-dwelling older adults.**

Keywords—augmented reality, virtual reality, elderly, exergames, fall risk, user experience, evaluation

I. INTRODUCTION

Falls are a real danger to the level of well-being in elderly, typically resulting in a deterioration in personal care as well as in physical and social activities. Although the causes of falls are multifaceted, outstanding inherent fall-risk aspects are age-related declines like those related to balance maintenance, posture control, and cognitive ability [1]. Various physical exercising programs, tailored explicitly for the elderly, have been developed, as fall prevention measures, to increase the muscle strength of the lower limbs, to enhance balance control and to increase motion range [2].

However, exercise interventions may be compromised by insufficient exercise amount and low adherence. The use of exergames (i.e., exercising via playing games) has been suggested as an alternative that can keep the training motivation high. Technologies such as balance boards, motion tracking sensors, augmented and virtual reality are increasingly used as alternative and more enjoyable ways of physical and cognitive exercising for elderly fall prevention compared to conventional methods [3].

Virtual reality (VR) and augmented reality (AR) are immersive technologies that are related but also have distinct characteristics in terms of application creation [4]. VR represents an immersive, interactive and computer-mediated experience in which a user perceives a simulated environment through special human-computer interaction equipment. One can interact with virtual objects in this environment as if they were real. A virtual environment can be displayed on a head-mounted display or VR glasses but a high-resolution display can be also used where an immersive feeling can be obtained through detailed 3D graphics. Head and hand tracking systems are used to allow the user to observe, move and manipulate the virtual environment. On the other hand, AR takes digital or computer-generated information, such as images, sound, video, or tactile perceptions, and overlays it in a real-time environment. AR technically most commonly is used to enhance the visual experience. Unlike VR, AR allows the user to view the real world, with virtual objects superimposed on or combined with the real world.

Both VR and AR have the potential to serve as technologies upon which to build motor and cognitive training programs in the form of exergames. Consequently, the training effects in principle can be more easily transferred in real-life environments. Furthermore, by adding gamification features to the training process could provide motivation to the participants to increase their engagement in the training. Nonetheless, various obstacles regarding the use of immersive technologies, in particular that of VR, in formal rehabilitation have also been reported, including the complexity of technical setup, VR sickness and the suitability of the technologies for the elderly population [5].

978-1-6654-6975-3/22/$31.00 ©2022 IEEE

In this study, evidence is provided on the feasibility, acceptability and safety of exergames developed in the context of GAME2AWE platform. The approach leverages on both AR and VR technologies to build a versatile tool for elderly fall prevention. In the next section related work is presented followed by the presentation of the AR/VR-based exergames developed. These exergames involve dual task activities and are anticipated to foster improvements in motor and cognitive functions of the targeted end-users. The results of an evaluation of the exergames is presented in terms of usability, tolerability and applicability. Finally, our conclusions and plans for future work are given.

II. Related Work

A literature review on systems that are using AR and VR technologies to build exergames for the elderly was performed, in order to frame the research area of GAME2AWE platform.

An AR-based exergame system which was specially designed to reduce fall risk for the elderly was presented in [6]. 3D models of the elderly were captured using the Kinect 2.0 sensor and were immersed in an interactive virtual environment. The system supported three game scenarios. The first is avoiding the wall, where the players have to stand appropriately to fit through a hole in a wall that comes towards them. In the second scenario, they must pick fruits, by moving sideways towards them as they appear. The third scenario involves stomping rats as they emerge from holes in the soil. The system aims to help players improve their muscle strength and develop their motor and cognitive skills. The first two scenarios also help to practice balance. The system was assessed positively in terms of user experience in a study that involved 25 elderly over the age of 65 years.

A different study explored exergame prototypes with activities performed in both AR and VR settings in order to determine the needs and preferences for an exergame platform targeting elderly with coexisting health conditions such as hypertension [7]. The participants were elderly without cognitive or stability problems. Two of the exergames required the elderly to perform squats in an execution zone of both a VR and an AR environment. A third exergame required seated trunk rotations in a VR environment. The analysis of the qualitative data collected through interviews identified vital requirements in terms of system technology, gamification and monitoring. Regarding gamification, the participants wanted to be able to compare their performance with their previous scores after completing the activities. They perceived the storytelling aspect of the game as very important and preferred a video tutorial instead of a manual to learn the game. During the game, health data like heart rate were monitored using a smart-band.

A scenario based exergame prototype with gamification elements was developed leveraging on AR and Internet of Things technologies [8]. Two game scenarios were developed as a proof of concept. In the first scenario, the user must climb a staircase by walking with high-knees on the spot. The second scenario requires the user to appropriately move the shoulders and elbows to fly like a parrot in a canyon environment. In addition, a smart wristband and Arduino-powered foot pressure sensors were used to measure users' heart rate and balance condition for possible fall detection. A user testing of the prototype was performed with 3 participants and the feedback provided will be used in the next development cycle.

Design considerations and applicability issues regarding the development of AR and VR exergames aiming to rehabilitate seniors with balance issues were discussed by Pereira et al. [9]. An exergame involving popping of balloons was developed in different immersive AR and VR configurations with the purpose of understanding the key design issues and supporting its evaluation by physiotherapists to assess exergame applicability for older fallers. The game requires moving around the scene to touch ascending balloons with the controllers in hands, in case of the VR version, or with plain hand gestures, in case of the AR version. In both cases appropriate headsets are required to play the exergame. Evaluation findings have shown a positive prospect as well as the necessity for technical improvements like the use of more convenient headsets and the addition of more cognitive and physical activities.

A participatory design approach with the involvement of relevant stakeholders (i.e., elderly with dementia, exercise specialists, content developers and researchers in the creation of VR exergames) was followed to co-develop VR exergames to engage demented elderly persons in physical practicing that fosters muscle strength, upper limb elasticity and endurance [10]. A VR exergame called Seas the Day was developed that placed users in a tropical virtual reality setting where they can perform three activities for 15 minutes. The players executed Tai-Chi moves to warm up, then they did rowing exercises, which train the muscles and the last activity was fishing, which involved neck rotations, elbow flexion, and elbow extensions. User experience was assessed by 5 community-dwelling older adults who besides playtesting the exergame they assisted in defining a protocol for remote deployment and assessment of the system.

The use of VR technology for motor and balance rehabilitation of elderly after a mild stroke was explored in a prototype exergame developed to assist professionals in the motivation of patients during training sessions [11]. The exergame includes six activities that were integrated in an immersive scenario that requires the interaction with virtual elements spread around the users' space. Half of the activities focus on training the upper limbs with movements of the shoulders, elbows, and wrists. The other half of activities exercise the lower limbs such as the legs through appropriate hip movements or the knees and hips to help patients improve their balance. The Kinect sensor was used to recognize and map the user movements during the gameplay. A pilot study was conducted to test part of the exergame functionality and to assess the user experience with different visualization devices.

All the examined studies had target groups of older adults. Most AR games used the Kinect motion sensor to detect the user's movements in terms of hardware. Motion detection in VR games was often handled with VR controllers. The exercises were paired with cognitive components in several studies, and all required upper and lower limbs movement. Several studies have also explicitly referred to balance, which has been targeted through appropriate exercises.

III. AR & VR-Based Exergames in GAME2AWE Platform

The work presented here is part of the GAME2AWE platform which has been developed with the aim to support 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. The design and development of the GAME2AWE platform was based on the principles of participatory and human-centered design. 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 [12]. Next, representative scenarios were selected to meet the GAME2AWE objectives and presented for feedback to end users and healthcare experts within a focus group [13]. The data collected from the workings of the focus group were analyzed to derive the basic guidelines for 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 as well as from the relevant literature [14] 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., on spot walking), 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 on spot walking in standing or sitting position, rowing in standing or sitting position, weight shifting in standing or sitting position, stepping forwards, backwards and sideways, standing on one leg, squatting, flank stretching, etc. Thus, the research hypothesis is that by 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 the elderly people to reduce fall risk.

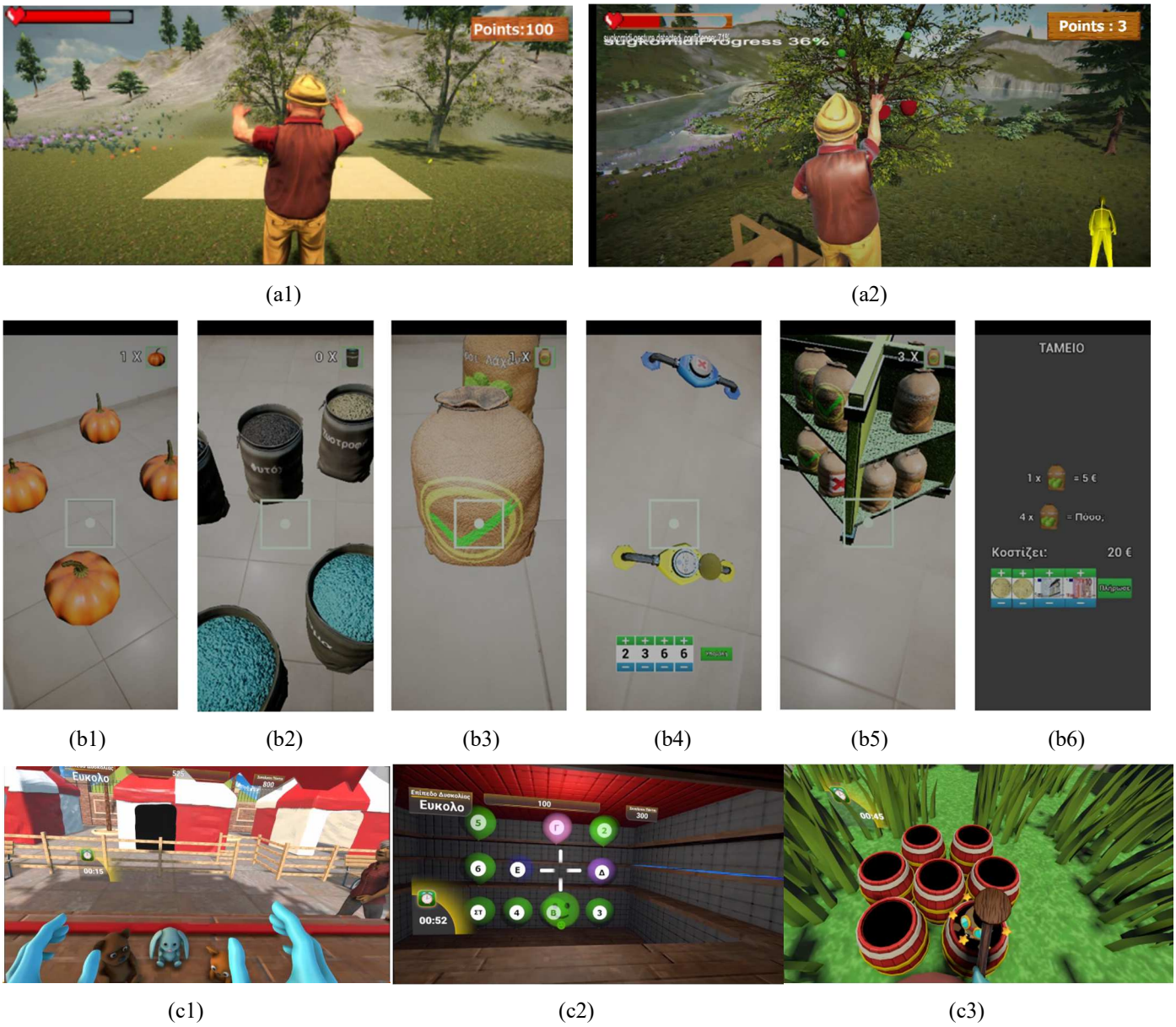
GAME2AWE proposes a combination of AR and VR technologies providing the user with a greater variety of exercises and immersive interactions. Such interactions can facilitate the implementation of game scenarios in a way that motivates and enhances users' engagement while making the platform easy to use. Motivation is also served by implementing gamification elements such as scenario-based tasks, difficulty levels, points, leader boards, avatars and target randomization.

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. Examples are: 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; the Darts game in which the player is asked to throw and burst in a certain order 12 balloons, six of which are numbers and six are letters of the alphabet; the Whack a mole game in which the goal is to stomp the moles away when they appear in random positions. These games are implemented using VR technology. Fig. 1 shows snapshots from example exergames in the platform.

AR can provide a high degree of embodiment and spatial sense of presence in terms of user experience. Microsoft Kinect sensor was used to capture 3D models of the elderly and embody them in interactive virtual environments of the "Life on a Farm" theme. This device allows users to interact with computer applications only with gestures, movements and voice commands without the need of explicitly handling a controller unit. For our games the second version of the sensor was used which is equipped with a richer SDK API providing the ability to track more joints and identify a variety of body states. An example game in this category is the Olive Harvest game (Fig. 1a1). The mechanics of the game incorporate movements which were selected as appropriate exercises for fall prevention while at the same time serving a specific goal in the gameplay. For example, side steps are used for selecting a tree to harvest. A rowing movement is used for spreading the olive collection sheet, while arms lifting is used for harvesting crops.

Part of the farming activities were explored using a mobile AR application that fused the real environment with virtual objects. Detecting objects spawned in space was done via ray casting with a limited range. Thus, to interact with the various objects, the user is forced to move towards them and reach them. Some activities require additional moves because the objects are not immediately apparent. In the sacks of fertilizer collection activity, for example, a certain number of sacks of fertilizers and additional sacks of other supplies such as charcoal, lime, and animal feed appear on the floor (Fig. 1b2). The player must go near the fertilizer sacks and target them with the mobile camera to collect them. The sacks of fertilizer can be identified by the label of the sacks and by the texture on their open top. As another example, in the water meter reading activity, one or two colored water meters appear on the floor, depending on the difficulty level (Fig. 1b4). The players must go close and crouch to the correct counter, based on the requested color, to open its lid by targeting it with the mobile camera. Then they must copy the indication in the user interface that appeared on the lower part of the screen on their mobile. Motor skills involved in such activities include walking in the room, movement coordination, bending or squatting. Cognitive skills involved include visuospatial orientation, attention, short and working memory.

Oculus Quest 2 technology by Facebook was used to develop the VR games. Oculus Quest 2 is a wireless standalone VR headset with a low weight of about 500g that creates virtual environments with the ability to navigate and interact with objects within them. It supports advanced calibration features by including inside-out tracking technology (i.e., cameras in the headset) to provide automatic calibration of the user position. Its operation requires two controllers for motion detection and a WiFi network and can be used autonomously without requiring a base game station to set up the game area. Following the recommendations of the manufacturer a game area of about 5 m^2 was tagged. 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.



(a1) (a2)

(b1) (b2) (b3) (b4) (b5) (b6)

(c1) (c2) (c3)

Fig. 1. Snapshots from example exergames in the GAME2AWE platform. The screens in the first row represent activities in the "Life on a Farm" theme implemented as desktop AR-based exergames: (a1) "Olive Harvest" game; (a2) "Fruit Harvest" game. The screens in the second row represent activities in the "Life on a Farm" theme implemented as a mobile AR-based exergame: (b1) Crop selection; (b2) Sacks of fertilizer collection; (b3) Sacks of seeds collection; (b4) Water meter reading; (b5) Selecting sacks of seeds to purchase; (b6) Payment screen for the seeds. The screens in the third row represent activities in the "Fun Park Tour" theme implemented as VR-based exergames: (c1) "Bazaar" game; (c2) "Darts" game; (c3) "Whack a mole" game.

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. 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.

IV. Evaluation

An evaluation study took place in the facilities of an elderly care center with twelve participants (N=12) which were categorized as end users (i.e., healthy older adults) and healthcare experts including a physiotherapist, an orthopedic doctor, a psychologist and an exercise professional. Demographics are shown in TABLE I. The purpose of the evaluation was to test the current version of the exergames in order to evaluate their functionality and usability in a pre-pilot stage. All participants gave their informed written consent prior

to participation in the study. The evaluation examined the following aspects of the exergames: usability, tolerability and applicability.

TABLE I. DEMOGRAPHICS OF THE PARTICIPANTS

Property	End Users	Experts
N	8	4
Age (mean ±stdev)	71.3 ±4.3	38.3 ±4.9
Gender (female/male)	6/2	2/2
Education years	9.4 ±3.7	≥16
Technology familiarity*	1.8 ±1.0	4

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

Before starting the testing of an exergame, a member of the research team provided an explanation of its goal and described how the game works. This was followed by a short demonstration of the game scenario and then the participants were engaged. During the game, feedback and assistance were provided whenever necessary by the development team. The evaluation study was completed in two consecutive days and the total time allocated for testing the exergames was 8 hours. The vast majority of the games had a duration between 1.5-3 minutes and short breaks were taken in between them. Fig. 2 illustrates an indicative instance point from the evaluation study.

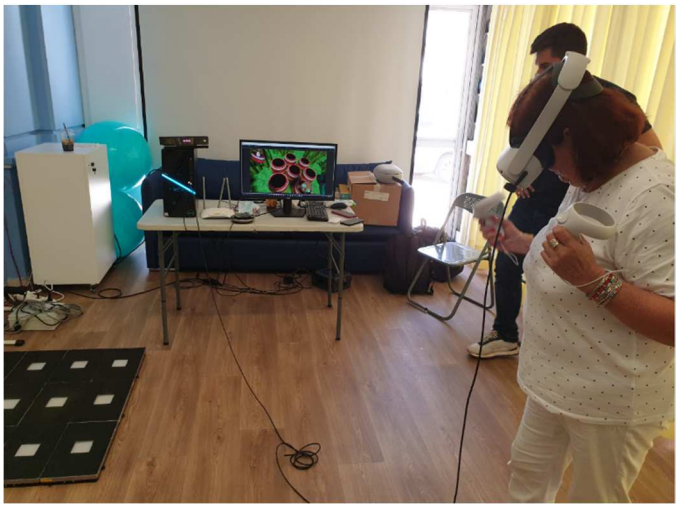


Fig. 2. Snapshot from the evaluation study.

Perceived usability and usefulness was assessed using the System Usability Scale (SUS) questionnaire [15]. The questionnaire includes ten statements (Fig. 3) 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). The rating for each statement was transformed so that the original total scores on the 0–40 scale were converted to the 0–100 scale according to best practices [16]. An above average SUS score suggesting a good usability is a score above 68.

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

Fig. 3. SUS questionnaire statements.

The SUS results for the exergames tested are shown in TABLE II. The mean SUS score is above 80 for both end users and experts suggesting a very high user acceptance by both groups. The data point out that the objectives of the exergames are clearly perceived and are sufficiently engaging to be pursued. Analysis of this feedback shows that participants believe that the complexity of the exergames is low, the game platform is understandable in terms of its functions and does not require much effort to use. On the other hand, a clear concern emerges from the answers of the end users to statement S4 (mean value 3.5±1.5). Since this item determines the participants' ability to use the system independently, it is interpreted that it may reflect the low technological familiarity that characterizes the majority of the participants and the general viewpoint that new technology may cause anxiety to older people. This may also explain the fact that the mean SUS score for end users is lower than that of experts.

TABLE II. SUS RESULTS

	Mean	SD	Min	25%	Median	75%	Max
End Users	82.8	12.3	57.5	78.8	86.3	89.4	95.0
Experts	86.9	3.1	82.5	86.3	87.5	88.1	90.0
Total	84.2	10.1	57.5	81.9	87.5	88.1	95.0

The tolerability of the participants in the VR-based training was measured using the Virtual Reality Sickness Questionnaire (VRSQ) [17] as simulator sickness is the most common undesirable effect reported when using VR environments [18]. The VRSQ assesses nine different simulator sickness symptoms, including general discomfort, fatigue, headache, eye strain, etc. 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). By adding all item scores, a total score is computed and then is converted to a percentage score. Higher severity in VR sickness is indicated by a higher score. In addition, an open-ended question was asked to the participants (i.e., "Did you experience any unpleasant symptoms during and after the VR-based training?") at the end of the evaluation to identify other possible poor effects.

Regarding unpleasant effects, the majority of the end users (63%) never suffered any symptoms of VR sickness. On the whole, only mild symptoms were experienced by those who reported such symptoms, as identified by a mean VRSQ score in the end user group (N=8) of 2.92/100 (STDEV 4.03). As shown in Fig. 4, the answers of VRSQ indicate that there were a

few cases of slight discomfort with eye strain having the biggest percentage.

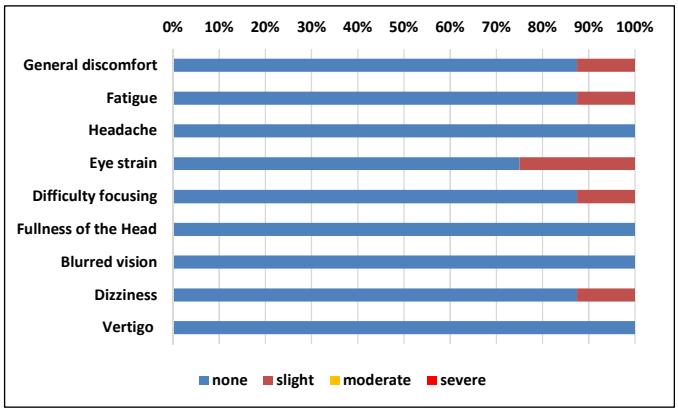


Fig. 4. VRSQ results for the end users.

The applicability of the exergames was assessed through an evaluation interview with the domain experts after testing all the exergames. The interview focused on the applicability of the exergames for elderly training to reduce fall risk with questions on topics such as the suitability of the exercises, the effectiveness and safety of the movements, the appropriateness of the difficulty levels and how well the movements are integrated in the gameplay. The feedback provided was positive suggesting that the exercises integrated in the exergames were safe to perform and could improve postural control and assist the elderly to reinforce their strength and balance and consequently reduce frailties and fall risk. This was actually expected since a participatory design approach had been followed for the design of the games targeting to a high usability and applicability of the exergames [13].

Some directions for improvement that were suggested include the provision of a greater variety of game content, the integration of new movements suggested by the physician and the addition of more difficulty levels than those presented, as more competent seniors found the effort required by the tasks in some games quite easy.

V. Conclusions

The evaluation study presented results that indicate a positive assessment for the immersive VR and AR-based exergames of the GAME2AWE platform by both end-users and healthcare experts. A pilot evaluation of the final developed exergame platform in the near future will provide more sound evidence on the usefulness of the proposed exergames in relation to fall prevention. The evaluation methodology includes a control group and an intervention group applying a randomized controlled trial. For all users, measurements of motor and cognitive functions will be recorded before and after using the exergame platform. Measurable success metrics of the game platform will be to achieve improvement on indicators of motor and cognitive functions.

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