Virtual Reality and Augmented Reality Exergames for older fallers: considerations about design and applicability by physical therapists

Guido Augusto Faria Pereira
Electronic Systems Engineering
School of Engineering
Universidade de São Paulo
São Paulo, São Paulo
guido.a.pereira@gmail.com

Jéssica Maria Ribeiro Bacha
Department of Physical Therapy, Speech and Occupational Therapy
School of Medicine
Universidade de São Paulo
São Paulo, São Paulo
jessicarbacha@usp.br

Izaura Beatriz Araújo Novais Silva
Department of Physical Therapy, Speech and Occupational Therapy
School of Medicine
Universidade de São Paulo
São Paulo, São Paulo
izaura.beatriz@fm.usp.br

Da Hee Chun Kim
Department of Physical Therapy, Speech and Occupational Therapy
School of Medicine
Universidade de São Paulo
São Paulo, São Paulo
dahee1998@usp.br

José Eduardo Pompeu
Department of Physical Therapy, Speech and Occupational Therapy
School of Medicine
Universidade de São Paulo
São Paulo, São Paulo
j.e.pompeu@usp.br

Roseli de Deus Lopes
Electronic Systems Engineering
School of Engineering
Universidade de São Paulo
São Paulo, São Paulo
roseli.lopes@usp.br

***Abstract*— This work investigates the application of virtual reality (VR) and augmented reality (AR) exergames for older fallers, through a literature review and an exploratory technological research. We developed an exergame called BALLOONS to understand the main design concerns and to be able to evaluate the applicability based on physical therapists evaluation. Three different immersive systems running the same game BALLONS were implemented, two as VR exergames and one as an AR exergame. Test and evaluation sessions were conducted with eleven physiotherapists. The results point to a positive evaluation by experts in terms of safety, tolerability, and acceptability. The findings also suggest the need for technical improvements, such as the development of lighter and more comfortable headsets, to increase acceptability and the need of a larger variety of cognitive activities and frequency adjustments of physical exercise, to increase applicability and value for rehabilitation.**

***Keywords*— Aged, Accidental Falls, Virtual Reality, Virtual Reality Exposure Therapy, Rehabilitation.**

I. Introduction

The increase in life expectancy has been observed worldwide and has led to an inversion of the population pyramids of several countries around the world [1]. The aging process causes several physiological changes that may have important health consequences, such as those associated with posture control and balance maintenance, as well as cognitive deficits [2]. Conventional physiotherapy for older fallers focuses on improving balance and mobility and consists of therapeutic exercises to increase strength and range of motion [3]. It is known that the cognitive deficit is also linked to an increase in the risk of falls [3]. Physical therapy for older people has treatments and exercises aimed at preventing falls [4], [5].

However, exercise intervention programs that tackle the issue to prevent falls in older non-fallers still have some challenges such as “poor program adherence” and “insufficient exercise intensity” that can compromise the intervention [4], [5]. Playing exergames has been an alternative [6] and suggests that playing video games can keep motivation in intrinsic ways [7] and that older adults could learn how to use technology in the same ways as young people, but the emphasis should be on learning time to familiarize and on positive feedback to avoid the fear of technology [8] ,[9]. Authors state that the use of this type of technology may be effective in reducing the risk and incidence of falls in conventional physiotherapeutic treatment [4],[7],[10]-[14].

The authors point out that an advantage is that it offers a controlled environment in which it is possible to manipulate the stimuli and the difficulty progression of the proposed exercise to the patient [10]-[14]. Thus, they state that the user's progress assessment becomes much clearer, in a way that helps the therapist to better plan his/her intervention [10]-[14].

One of the limitations of the exergames commonly used is that the equipment, and usually also the game (software implementation of the game), used to implement them are from the entertainment industry and were not designed for clinical rehabilitation [15], therefore, they do not contain the degree of specificity necessary to perform the function of rehabilitating patients with cognitive-motor deficits [16] and frequently become unavailable in a short period of time because the entertainment industry moves fast to sell new products.

II. Designing Exergames for Older Adults

Recent studies have shown that the use of exergames can be beneficial in restoring balance and reducing the risk and frequency of falls in conventional physiotherapy [9],[13],[17]-[21]. Exergames involve dual-task motor and cognitive activities and may promote improvement in cognitive-motor function, degree of independence and adherence of individuals to therapy [13].

One of the drawbacks of exergames widely used today is that they have not been optimized for clinical recovery [22] and therefore do not provide the degree of precision required for the rehabilitation of patients with cognitive-motor deficits [21]. In addition, commercial exercises are not being developed specifically for cognitive-motor training for older adults and neurological patients [21].

In this paper we present considerations about design and applicabilty based on results of an ongoing research and development of immersive exercise with cognitive-motor exergame solutions aimed at older fallers.

III. Study Design

This research applied a mixed-methods survey-based study, through interviews and questionnaires, in order to acquire both qualitative and quantitative data. This study had two data collection sessions, as presented in Table I. In Session 1, we applied the first version of the developed game, BALLOONS v1.0, installed in two different virtual reality hardware solutions, S1-VR and S2-VR_ODT, with a session of six physical therapists (participants P1-P6), three of them starting with S1-VR and the other three with S2-VR_ODT. In Session 2, we applied an improved version of the game, BALLOONS v1.1, installed in the two different virtual reality hardware solutions and one augmented reality hardware solution, S1-VR, S2-VR_ODT and S3-AR, with 8 physical therapists (P3,P4,P6,P7-P11), in different sequence testing order.

TABLE I. Participants, testing order and systems.

Sessions	*BALLONS game version*	*Participants*	*Testing sequence* 1st	2nd	3rd
1	V1.0	P1, P2, P3	S1-VR	S2-VR_ODT	---
		P4, P5, P6	S2-VR_ODT	S1-VR	---
2	V1.1	P7, P8	S1-VR	S3-AR	---
		P3, P6	S3-AR	S2-VR	---
		P9, P10, P11	S1-VR	S3-AR	S2-VR_ODT
		P4	S3-AR	S1-VR	S2-VR_ODT

A. Ethical approval and consent to participate

This study was approved by the Ethics Committee of the Medical School - Universidade de São Paulo, Brazil 3.138.105 Certificate of Presentation for Ethical Appreciation (CAAE): 03310818.0000.0065.

B. Study settings

The study was conducted at the Motor Behavior Lab (LACOM) - School of Physical Education and Sports in partnership with the Interdisciplinary Center of Interactive Technologies (CITI), both at Universidade de São Paulo (USP), Brazil.

C. Instruments for data collection

In order to evaluate safety, tolerability, and acceptability, different instruments were used, all of them in the brazilian portuguese language, some were based on or adapted.

Q1 - Pre-virtual reality discomfort questionnaire, based on the "Questions of the Motion Sickness Screening Questionnaire" and extracted from Da Costa et al. [23], was used to map susceptibility to nausea and motion sickness.

Q2 - Technology use questionnaire, based on the "Questions of the Technology Use Profile Questionnaire" and extracted from Da Costa et al. [23], was used to examine familiarity with video game and VR headsets and/or discomfort with VR.

Q3 - Post-test questionnaires, divided in three parts A to C, were applied after the use of a specific solution.

Q3-A - Discomfort questionnaire after virtual reality (safety and tolerability) was used to collect levels of any health side effects or any physical discomforts, applies a Likert scale of intensity and was based on Da Costa et al. [23].

Q3-B - Satisfaction questionnaire (acceptability), a 10-item questionnaire with five response options for respondents from strongly agree to strongly disagree based on the System Usability Scale (SUS) [26], was used to evaluate if the game is acceptable to users. In order to measure the perceived intensity of the physical activity, we added a yes or no answer to question 11 "did physical exercise to be able to perform the tasks of the game" from Q3-B and ask in sequence "How intense was the physical exercise" in a Borg CR10 Scale [27].

Q3-C - Satisfaction Interview (acceptability) was applied each time after a system was tested with questions based on Da Costa et al. [23] to search potential and possibilities of using the game in clinics, home as part of their patient treatment, as well if the specialists like or dislike anything about the game. Question 15 was not asked for being considered redundant to question 12 and 13. Answers were asked to be in a written format, but interviewed participants could also speak their mind if they feel necessary.

Q4 - Questionnaire and evaluation interview of physiotherapists (applicability), divided in two parts A and B, was applied to each participant at the end, after testing all systems in the specific session.

Q4-A – Questionnaire, was based on Systems Framework for Postural Control (SFPC) presented on Sibley 2015 [28] and Tahmosybayat [29].

Q4-B – Interview, focus on applicability to patient treatment with questions [30] elaborated by Prof. José Eduardo Pompeu, one of this paper's authors, the participants were asked to answer in a written format, but they could also speak their mind if they felt necessary.

D. Requirements for the exergame

There are five requirements that should guide the design and development of an exercise for balance, as stated by Choi [18]: (1) exercise intensity; (2) attendance; (3) safety; (4) engagement; (5) easy to do. It is important to keep these requirements in mind when mapping the problems and difficulties while developing and testing technological solutions for rehabilitation. All of them hamper the development of an effective rehabilitation treatment: the exercises must engage the patient from beginning to the end, while promoting repetitive, safe and efficient motor-cognitive activities, respecting the specificities of each patient.

IV. Exergame BALLOONS

BALLOONS is a game for cognitive-motor training that invites the user to play in a virtual world filled with colored balloons. Using two manual controls (one for each hand), the user can interact with the balloons, popping them and gathering points. Before the chronometer starts, the player must explore the environment to familiarize himself with the scenario and the mechanisms of communication and interaction. To start, the player must touch a white cube, which disappears, and the game and chronometer start in three seconds. Balloons will appear spontaneously, shifting from bottom to top, just like helium balloons in real life. The player needs to think and respond, moving around the scene to reach the balloons with the controllers in their hands, popping balloons until the required sum is reached to score game points. To score, the player needs to think and respond quickly by popping balloons until he reaches exactly the value (10 or 20) displayed on the players heads-up display (HUD), adding a layer of cognitive activity to the motor exergame.

The challenge is to interact with enough balloons until you gather a specific cumulative sum. Completing the sum exactly equal to the required amount will provide the same amount of points to the player (and one correct mark will be computed). On the other hand, if the player gathers more points than required – for instance, by popping a balloon with value 2 when the current gathering score needs just 1 to reach the specific sum (10 or 20), no points are given and another sequence starts if the total time was not reached.

In BALLOONS, the player must make the highest game score possible by popping balloons in a specified time (for example, for 5 minutes). In Figure 1 we present examples of images taken from the game BALLOONS v1.0 in virtual reality solutions and v1.1 in virtual reality and augmented reality solutions.

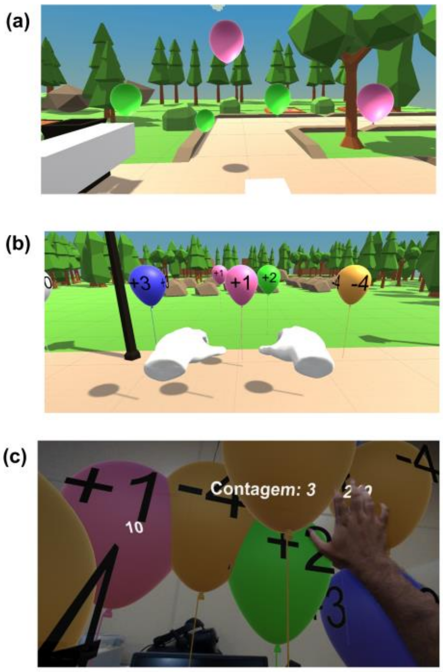

Fig. 1. Image examples from game BALLOONS in different implementations (a) BALLOONS v1.0 in virtual reality solutions (S1-VR and S2-VR_ODT), (b) BALLOONS v1.1 in virtual reality (S1-VR and S2-VR_ODT) and (c) BALLONS v1.1 in augmented reality (S3-AR).

A. Game modifications

Based on the evaluation of data collected from Session 1, the following improvements were implemented in BALLOONS to generate the new version v1.1: (1) further virtual controllers from the player's original position, avoiding accidental balloon popping; (2) sound feedback addition, to indicate correct and incorrect answers, and when the game is over; (3) human hands inclusion for the model game controllers for a more accurate position of the controllers to catch balloons; (4) more balloons inclusion with different values such as 0, +3, -4 and with a numeric indication for each color of every different balloon; (5) inclusion of balloons with negative values to increase difficulty and stimulate players' attention; (6) change of environment, placing objects further for players, to increase the need of more focus on collecting balloons and give the impression to move more to be able to explore the space of the virtual environment; (7) increase the time of each game session from 5 to 10 minutes; (8) change the score when players summed 10, including 3 times with the sum required as 20 (on which the players would receive 20 points for the right sum); (9) inclusion of an invisible game object as an invisible collider underneath the player to avoid surprised random balloon colliding player's virtual hand by accident and frustrating player.

B. Implemented System

We implemented different systems as hardware solutions for this work: two virtual reality solutions, S1-VR and S2-VR_ODT, and one augmented reality, S3-AR. In Figure 2 we present a participant using the three different solutions.

S1-VR used a virtual reality headset consisting of a head-mounted display (HMD) [31], the Samsung HMD Odyssey, from the Windows Mixed Reality platform, connected to a computer with the minimal requirements as recommended by [32]. For security reasons, a harness to hold the person that would be playing the game was included in the solution. S1-VR was designed mainly for postural training, because of the limitation of the walking area.

S2-VR_ODT used the same HMD as S1-VR and integrated another peripheral for walking for gait training, an Omnidirectional Treadmills (ODT) from Cyberith. An ODT is a mechanical device that allows a person to perform locomotive motion in any direction and is used in immersive virtual environment implementations to allow movement within the virtual space [33]. For security the ODT holds the participant in a three pillar of a ring in the middle where the person can walk in the expected walking direction. S2-VR_ODT solution was designed for gait training,

For the two VR solutions, S1-VR and S2-VR-ODT, the BALLOONS exergame was developed using Unity 3D 2018®, Microsoft Visual Studio 2017® and assets from Microsoft's tutorial asset for beginners' windows mixed reality.

S3-AR used the Meta 2 headset as an Augmented Reality Headset (ARH) for Augmented Reality (AR), connected to a computer following the minimal requirements [35], that allows users to access virtual and physical data overlaid [33]. In this solution, the participant can see the real environment and only the balloons overlaid, but not the other elements of the virtual scenario used in the VR solutions. This mediated dive positions digital assets around the physical world, increasing user interactions and experiences [34]. In this solution, there are no controllers, the headset detects hand gestures, meaning that the controllers are the user's hands. This is possible because of the front cameras and sensors on the headset. The information is displayed in front of a transparent glass that is in front of the user's eyes. that could see their reality mixed.

For the AR solution, S3-AR, the BALLOONS exergame used only the Meta SDK inside the Unity 3D 2018® for development.

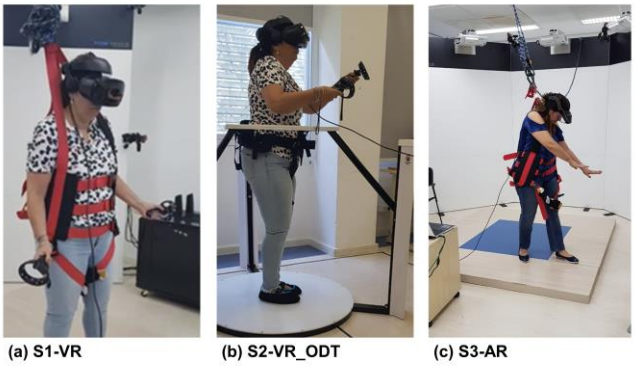

Fig. 2. Participants playing with the three different implemented solutions: (a) virtual reality S1-VR, (b) virtual reality with Omnidirectional Treadmills S2-VR_ODT, and (c) augmented reality S3-AR.

V. RESULTS

The initial results of this research, in the two test sessions, presented at Table I, confirmed the potential of these solutions for rehabilitation application at clinics for older fallers, accompanied with a health professional and as a supplement for treatment. However, the results also point out the existence of a lack of exercise intensity and the necessity of adding more cognitive activities and challenges to the game and content in all 3 solutions. Also, a better calibration of the exergame for the ODT is needed to make it easier to move and reduce the learning time required. Another technical issue is to use a lighter HMD and if possible, a wireless or all-in-one VR solution to eliminate difficulties with the connecting cable while practicing the rehabilitation exergame, and to be able to move even more freely and move their bodies with more intensity. In Session 2, the reported discomfort increased probably because the time of the session was two times longer than in Session 1.

VI. DISCUSSION

S1-VR was tested in both sessions 1 and 2. As presented in Fig. 3, in Session 1 the answers of Q3-A, indicate that there was no discomfort at all. However, in the answers of Session 2, there was some discomfort - tiredness insight shows the biggest percentage, these results probably resulted from an increased time and difficulty in BALLOONS v1.0.

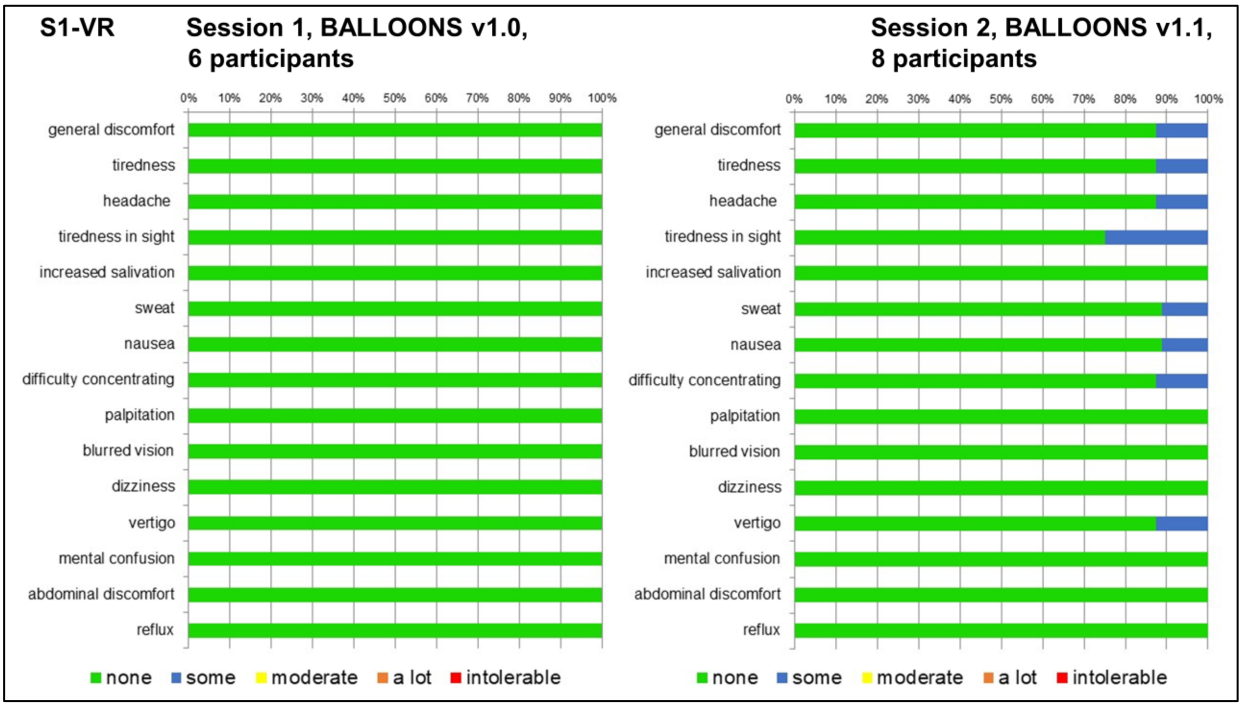

Fig. 3. Part A - Questionnaire of discomfort after virtual reality (safety and tolerability) (Q3-A)– Comparison of the two Sessions in S1-VR.

On the other hand, Q3-B data, in Fig. 4, to be on the contrary, question 10 and 11 in Session 1 are 50% in strongly in disagreeing to over 60% in Session 2. Despite increased game enjoyment and understanding of the game and easier to play in questions 1, 2 and 3 from Session 1 compared to Session 2. We can notice that the difficulty of the game has influenced because of the neutral response increase in questions 4 to 8. In question 7, Session 2, more people felt less safe. In contrast, in question 9 all users strongly agree that it is easy to use VR glasses.

The data indicates that players submitted in more constant movement probably felt less safe, decreasing the answer “strongly agree” and “agree” to “neutral” in some responses. Based on Q3-B Session 2 answers compared to Session 1, 50% to more 60% is the increase of strongly disagreeing that they did some physical activity. On the other hand, the percentage of strongly agreeing is 0% to over 20%, indicating that the individuals of the session have different opinions about what is considered physical activity. S1-VR needs improvement such as, game content, and exercise intensity. In addition, S1-VR is highly accepted by participants in both sessions and presents stable performance.

S2-VR_ODT was tested in both sessions 1 and 2. In Fig. 5, the data of Q3-A, session 1, it is noticeable that answers such as tiredness in sight, sweat, nausea, dizziness, and vertigo discomfort, are significantly better compared to session 2, because the increased time and difficulty added to the game for session 2.

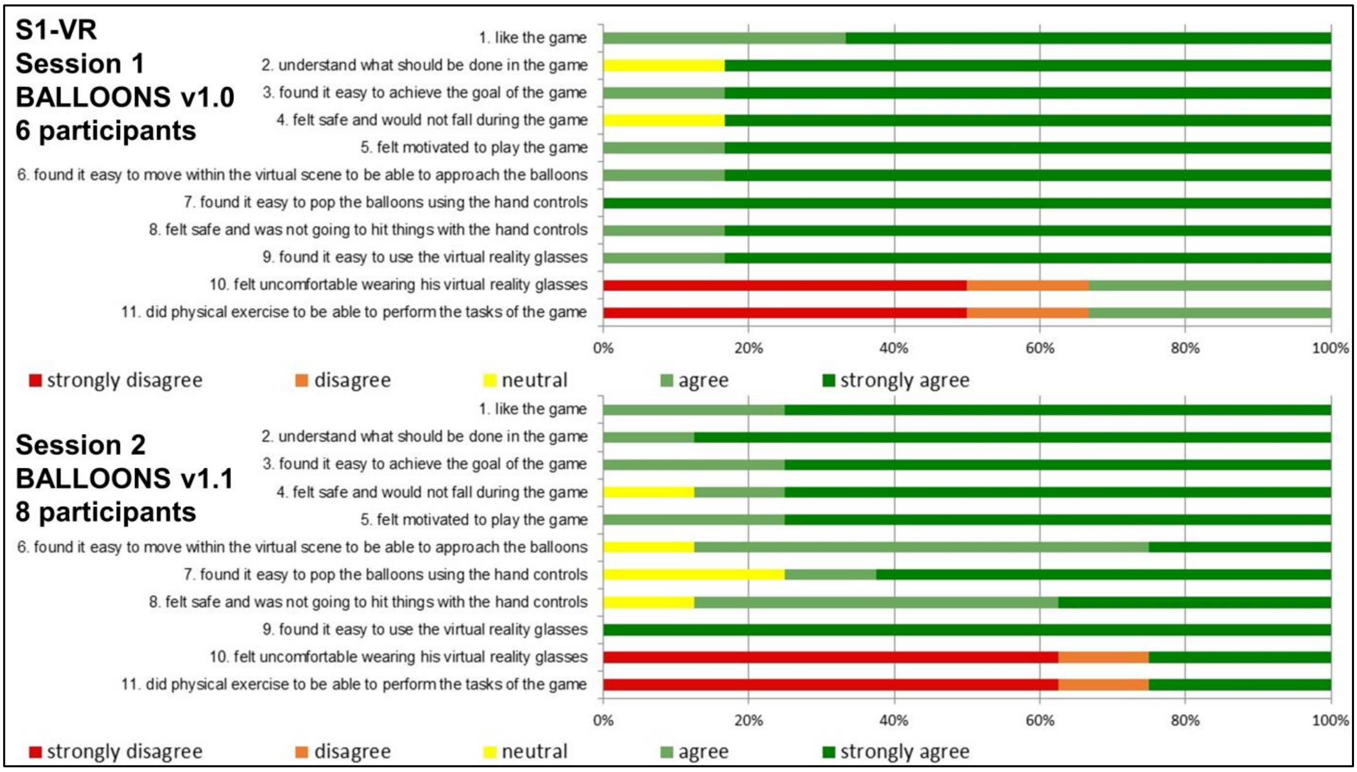

Fig. 4. Part B - Satisfaction questionnaire (acceptability) (Q3-B)- Comparison of the two Sessions in S1-VR.

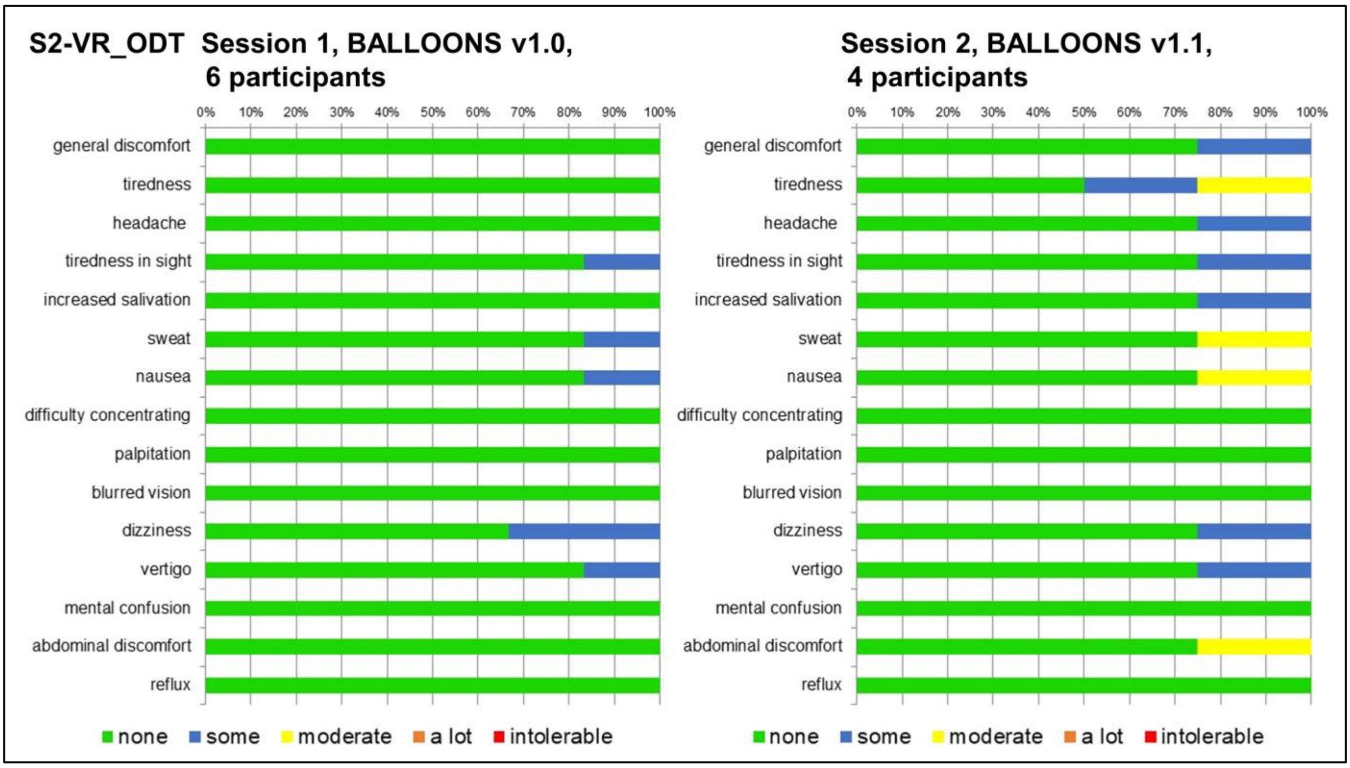

Fig. 5. Part A - Questionnaire of discomfort after virtual reality (safety and tolerability) (Q3-A) – Comparison of the two Sessions in S2-VR_ODT.

However, Q3-B data presented in Fig. 6 shows that question 10 and 11 in session 1 are 50% in strong agreement to over 70% in session 2, despite players' increases of game enjoyment and understanding of game and easier to play in questions 2 compared to session 2. What brings concern is that there are more strongly disagree with question 6.

Based on the answers of Q3-B in Session 2 compared to Session 1, overall present worse results. Increase of strongly disagree more than they did some physical activity, suggests that the participants in Session 2 have different perspectives and opinions, about what they could consider physical activity. On the other hand, participants had technical issues and had to learn how to use the ODT, could suggest why results were not satisfactory

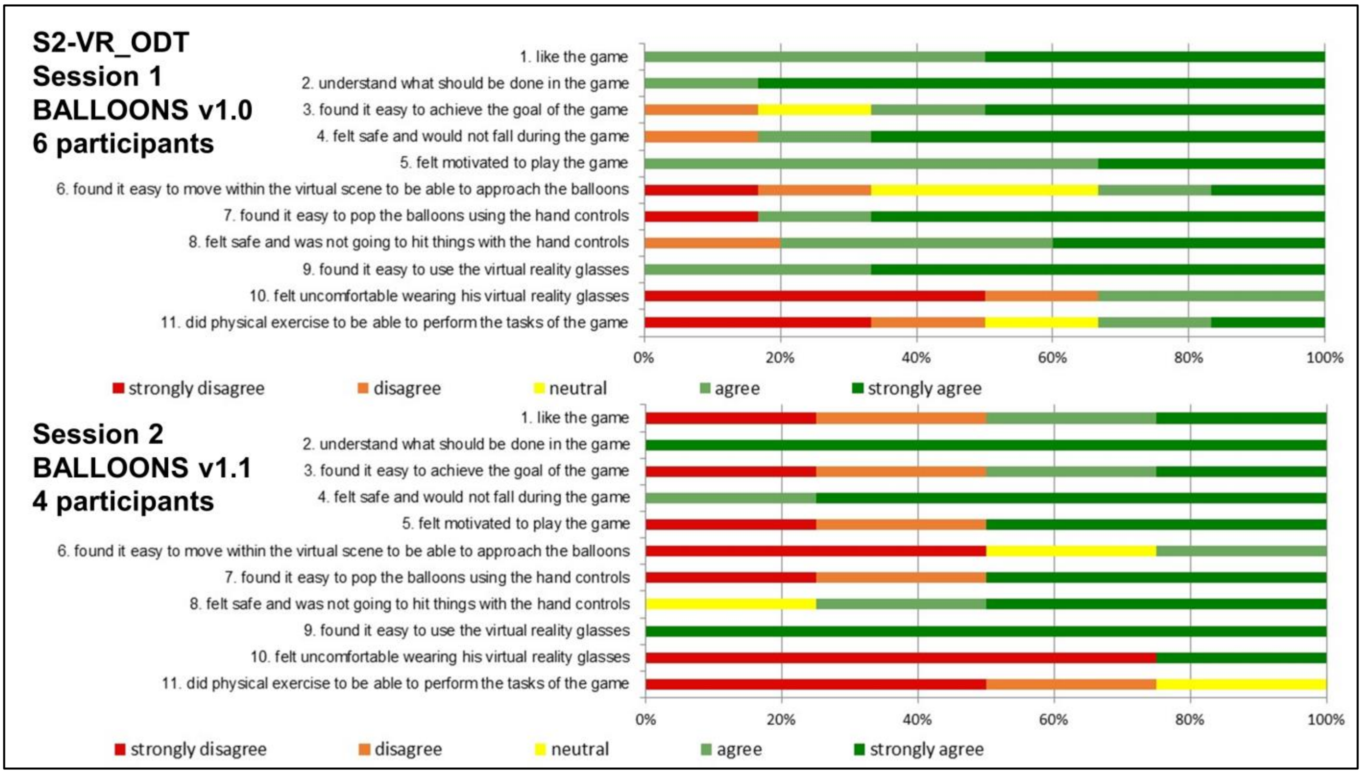

Fig. 6. Part B - Satisfaction questionnaire (acceptability) (Q3-B)- Comparison of the two Sessions in S2-VR_ODT.

S3-AR was used only in session 2. None of the participants had previous experience with the AR solution. In Fig. 7, Q3-A data point that there were some discomfort, however, percentages are lower or non-existing compared with those of VR solutions.

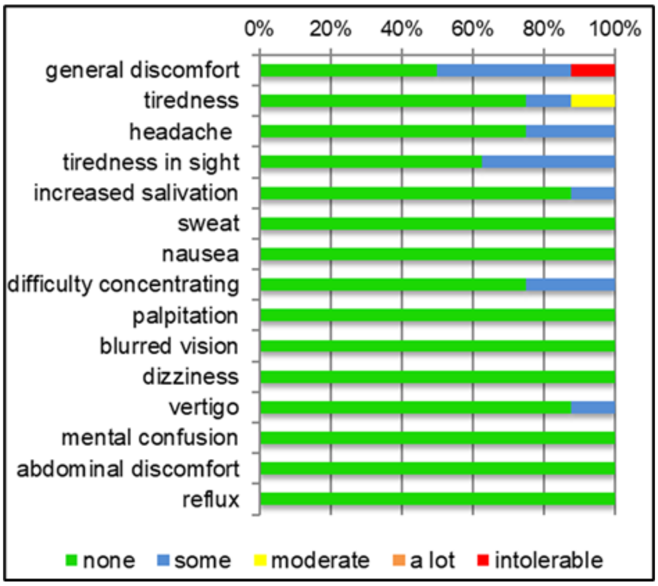

Fig. 7. Part A - Questionnaire of discomfort after virtual reality (safety and tolerability) (Q3-A) – S3-AR.

However, Fig. 8 from Q3-B data, shows that even being an AR system does not necessarily mean that it is a safer system or physically active. On the other hand, it was easy to understand what the activity was, felt motivated and safe. However, the enjoyment was low, and it felt hard to pop the balloons using hand gestures in this case. Most participants did not feel that they were doing physical activity.

Unfortunately, the technical issues overcome the experience, as well in S3-AR. Besides being less impactful. Another issue is interaction. Because of its different form of interaction, it is necessary to learn how to use it first, which impacts the experience. Besides the technical issues, S3-AR is a strong candidate despite its technical limitations and issues, for alternatives of players that are more sensitive to HMD.

VII. CONCLUSION AND FUTURE DIRECTIONS

The results presented in this research indicate positive assessment by experts in older fallers therapy, for the two immersive VR and one immersive AR implementations of the BALLOONS game. Based on the literature review and our practical observations, we suggest eight considerations for the design of an exergame for older fallers:

1) Must have health professionals involved in all stages of development.

2) Use strategies of rapid prototyping and successive iterations.

3) Use platforms that can be used for physical activity.

4) Give consistent visual feedback (users need to clearly perceive when they touch an object in the scenario).

5) Give preference to technologies that are more flexible to use and adapt and can be easily developed.

6) Develop the game as simply as possible, for flexibility to adapt in other platforms and to change the game based on feedback of the specialist.

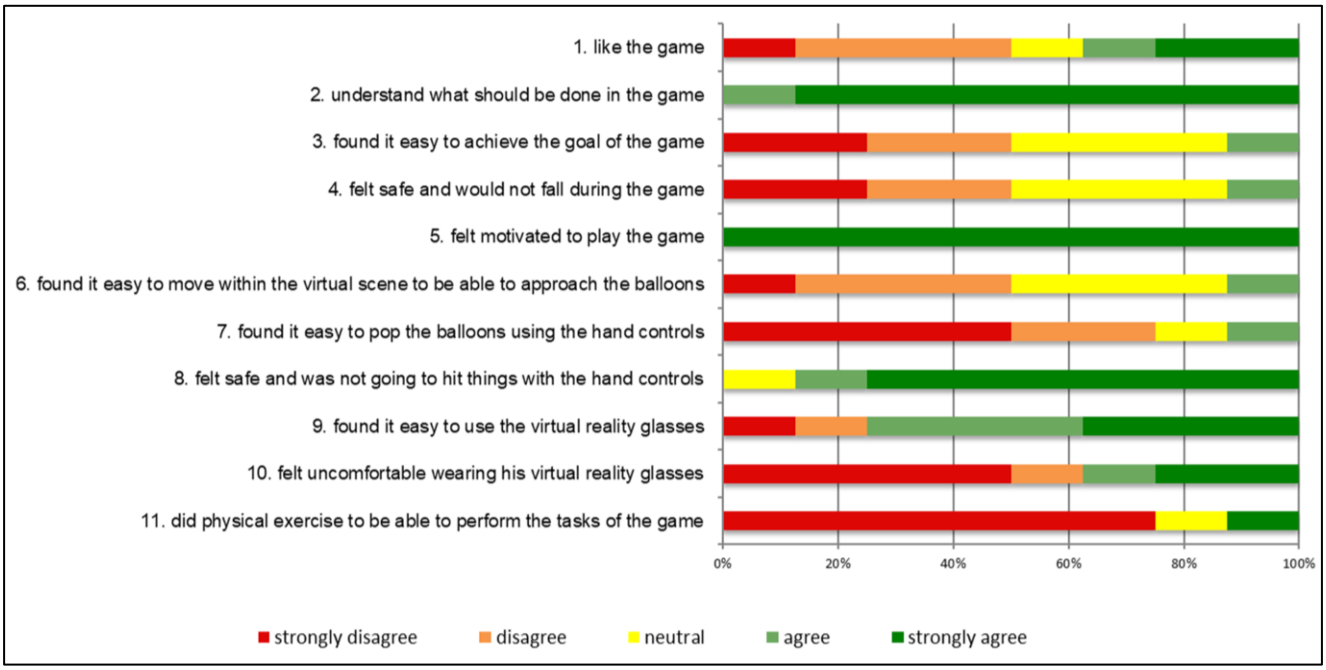

Fig. 8. Part B - Satisfaction questionnaire (acceptability)(Q3-B) – S3-AR.

7) Guarantee that participants will not have severe side effects.

8) Five requirements of Choi [18]: exercise intensity, attendance, safety, engagement, easy to do.

In addition, the main considerations for evaluation of an exergame for older faller adults, by rehabilitation specialists, to establish standardized evaluation procedures are the following four:

1) Safety assessment.

2) Tolerability.

3) Acceptability.

4) Applicability potential.

The BALLOONS game and its implementations developed for this research proved to be useful as platforms for further investigation on virtual rehabilitation for older faller adults and other rehabilitation applications.

These studies are important not just for physical therapy rehabilitation, but for VR in general, to better integrate the human body in immersive environments. One important aspect, for health applications, is the need for improvements to reach standards required, proven through scientific method as effective and advantageous for health professionals.

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