Received 15 October 2019; revised 7 October 2020; accepted 3 November 2020.
Date of publication 13 November 2020; date of current version 16 September 2021.

*Digital Object Identifier 10.1109/TETC.2020.3037962*

# A New Application for the Motor Rehabilitation at Home: Structure and Usability of Bal-App

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**ABSTRACT** The aim of this paper is to present an innovative tablet-based application with 360° videos for the motor rehabilitation of frail elderly, Bal-App. This app was developed for iPad and exploits the potentiality of 360° videos to improve balance in frail patients through several exercises with an increasing level of difficulty. The app includes 10 sessions to be played 3 times a week for 3 weeks. The results of the usability study are very encouraging, and patients are very interested in trying this app at home like a guide for the motor rehabilitation. Only few non-substantial adjustments before the clinical trial are planned.

**INDEX TERMS** Virtual reality, rehabilitation, ageing, frailty, usability, UX

## I. INTRODUCTION

### A. DEFINITION OF FRAILTY: PHENOMENON AND HEALTHY OUTCOMES

The proportion of Italian population over 65 years old is expected to significantly raise in the next 20 years [1]. Thus, the healthcare system will both face the growth of geriatric pathologies and their management [2]. Particularly, frailty is increasingly gaining attention. Although there is not a univocal definition yet, healthcare professionals have reached a consensus considering frailty a status of increased vulnerability resulting from increasing age, affecting both cognitive and motor domains (i.e., gait, balance and mobility) [3]. Although previously considered as synonyms, frailty, aging, disability, comorbidity are scientifically and clinically different phenomena [4], [5]. Older people are not necessarily more likely to get sick; they are more vulnerable if exposed to a stressor, both internal and external [6]. Frail people are far from being disabled since they maintain the ability to perform both activities of daily living (ADL) and instrumental activities of daily living (IADL) [7].

According to the definition proposed by Fried and colleagues (2001), frailty is a heterogeneous clinical syndrome characterized by phenotypic components [8], [9]: unintentional shrinking (or weight loss), weakness, poor endurance and energy, slowness and low physical activity. In everyday life, the ability to cope with acute stressors is compromised, and consequently, the risk of adverse outcome increases (e.g., falls, incidents, disability, hospitalization and mortality in a year) [10].

Specifically, it is considered frail an elder individual who presents at least 3 of the 5 above-mentioned symptoms; however, since frailty is not an irreversible syndrome, its early recognition might be helpful to delay its progression through proactive and anticipatory interventions [11]. Notably, reversal of the frailty may be also possible [10], [12], and regular physical activity can prevent functional decline and reduce the symptoms [13].

### B. HOME REHABILITATION AND TECHNOLOGY: A POSSIBLE SOLUTION

Home-based exercises are a useful tool to reduce frailty and fall risk in older adults, as well as to improve the motor

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parameters associated [13]. Home-based exercise programs constitute one of the most recent answers to the needs associated with an increasingly growing aging and frail population. These exercises guarantees independent home-living, leading to favorable outcomes in terms of quality of life [14], [15]: in fact, aging-in-place has been recognized as a sustainable organizational strategy, and healthcare assistance programs should follow this approach, promoting accessible at-home rehabilitation interventions that engage patients and favor treatment adherence [15], [16]. Virtual Reality (VR)-based devices and technologies might be considered useful tools that meet such needs, allowing aging-in-place and the integration of healthcare professional work [17], [18]. Research has widely recognized the potential of technology-based remote interventions, in order to improve elderlies' independent living [17]. Besides enhancing motivation and enjoyment, the added value of VR-based training concerns a repetitive and variable rehabilitation (promoting both motor learning and the ability to adapt to novel situations) [19]. Moreover, VR devices provide patients with an augmented feedback (e.g., visual, auditory) improving learning rates [19].

In recent years, many technologies for personal health care and aging have been proposed in order to prevent, reduce or help relieving some of the main conditions affecting elderly people. For instance, Standen and colleagues [20] recently provided an example of low-cost device for at-home rehabilitation for stroke patients with residual hand and arm impairments. Information and communications technologies (ICT), assistive technologies (AT) and human-computer interaction technologies (HCI) are frequently used in both research and clinical practice [21].

According to Pilotto and colleagues [21], nowadays the most encouraging clinical applications of technologies in geriatrics are housing and safety (to allow older people to remain in their homes and communities), mobility and rehabilitation (to improve mobility and gait), and communication and quality of life (to enable the reduction of isolation by promoting social interaction with the caregivers and fostering positive outcomes increasing the level of autonomy).

Moreover, several studies have already shown that frailty, mobility impairments and balance deficiencies increase the risk of falls in elderly [22], [23]. As Vincent and colleagues [24] highlighted, it is possible to reduce the risk of falling by improving balance and strength. These goals could also be achieved through a specific motor training led by a specialist, i.e., a physiotherapist. Unfortunately, it's hard for patients to continue this kind of training at home alone, with some predictable outcome.

Home exercises supported by technology can be effective for motor rehabilitation, and several related benefits have been reported [25]: technology solutions can enhance the compliance and the adherence, providing a treatment that is engaging. Furthermore, home-based exercises can be provided in an ecological setting, avoiding high costs of health care, and allowing elderly to get access to the rehabilitation every day, multiple times a day. Finally, the rehabilitation exercises can be customed to meet the patients' needs and adapted to the progresses made [26].

Nonetheless, considering that the target of the rehabilitation programs are frail older adults, the usability aspects must be a priority. According to Valladares-Rodriguez and colleagues [27], acceptability and usability are fundamental aspect to consider when trying to respond the user's needs with technological means. Indeed, any technology-based solution may be a dead end if target users reject it or have difficulties in using it.

### C. VIRTUAL REALITY AND 360° VIDEOS

360° video has been emerging as a new way of experiencing immersive videos. Thanks to the dual-lenses' cameras (that can capture a 360° x 180° field of view, instead of the limited viewpoint of a standard video recording) and to the availability of powerful handheld devices (such as smartphone or tablet), using these videos is becoming more and more frequent. They enable immersive "real life", "being there" experience for people by capturing a 360° view of the world. Users can dynamically change their viewpoint and look at any part of the captured scene they desire [28], [29].

Nowadays in VR applications, the contents are often generated by creating a 360° video panorama of a real-world scene [30].

Beyond all the criticisms, 360° videos can be immersive experiences activating a sense of presence that engages the users and allows them to focus on the virtual experience by making them feel as if he or she is physically part of the environment. Despite their increasing popularity, the use of 360° videos also implies cybersickness which, in turn, limits the experience to a maximum of 10-20 minutes (depending on one's own sensitivity) [28]. Moreover, 360° videos have not been properly considered a VR realistic technology, delivering a suboptimal experience. Presumably, elderlies' technological gap could decelerate or hinder the process of familiarization with the VR-based device. [28].

According to Higuera-Trujillo and colleagues [31], 360° panoramas and VR contents are closely similar to the physical environments (both in terms of psychological and physiological responses). Particularly, regarding the physiological responses (operationalized with Electrodermal Activity (EDA) and Heart Rate (HR) signals), the VR format reached the closest approximation to psychical life conditions, whereas 360° panorama led to the most accurate outcomes in terms of psychological responses (operationalized with Self-Mutilative Behavior [SMB] scale for environmental assessment and Pleasure Arousal Dominance [PAD] emotional state model).

In this perspective, another study [32] revealed the strong association between real and 360° environments. This research, conducted with functional Magnetic Resonance Imaging (fMRI), revealed that the 360° panoramas are an effective and ecological tool capable of eliciting the cortical areas involved in the visual memory for spatial associations as much as the reality is [32].

Despite the increased number of VR applications in the healthcare sector, evidence showing the potential of 360° immersive videos is lacking. Particularly in the field of rehabilitation, the benefits of 360° videos still have to be demonstrated, and challenges are open.

A recent research [33] investigated the role of 360° videos in encouraging the rehabilitation process, by testing the role of 360° immersive instructions videos (led by a rehabilitation therapist) in three groups: (i) healthy people (control group), (ii) patients with motor, (iii) and cardio-vascular impairments. Briefly, the results showed that 360° immersive videos successfully engaged patients, regardless to the rehabilitation trial they were currently enrolled in (motor or cardiovascular). These outcomes are thus encouraging for enhancing motivation and long-term exercise adherence, which is generally low, especially in-home exercise programs [34].

On the other hand, nowadays there is a consensus about the efficacy of balance and gait rehabilitation processes exploiting VR in neurologic patients [35]; improvements of static balance, gait components, sensorimotor integration and self-efficacy of falls have been reported after VR therapy in the elderly, with positive impact on mobility outcomes [36].

Based on these premises, the aim of the present work is to present and assess the usability of a tablet-based application, Bal-App. This tool is designed for home-based rehabilitation of frail subjects, in order to improve their balance. We based the protocol on a previous article of Pedroli and colleagues [37], involving a high-end technology for motor rehabilitation in hospital. The idea is to create a rehabilitative continuity between the hospital and the patient's home.

Usually 360° videos are experienced with a Head Mounted Display, but for dynamic motor rehabilitation this technology is not recommended for safety reasons (i.e., vision of the real-world is completely occluded). Thus, we decided to exploit the potentiality of a tablet in order to overcome this limitation by allowing the exploration of 360° videos without an immersive system. The following sections will further present the rationale that inspired the development of Bal-App. Specifically, Section II will thoroughly describe the application flow and architecture, with details regarding its development and a description of the tasks. Section III will provide the results of the usability test conducted on the Bal-App. Finally, Section IV summarizes the findings and suggests future research directions.

## II. BAL-APP

### A. APPLICATION FLOW

The equipment for the performance of the exercises at home was constituted by a portable cycle ergometer and an Apple IPad 2 tablet on which the app Bal-App was installed. The app was developed considering the difficulties that the target users may encounter while using the application and/or the devices. To limit the possibility of inappropriate adherence to the protocol, the choices that the user could make within each screen were limited or mandatory, but the possibility of choosing whether going on or stopping the session was left to the elderly. Moreover, to help the user in the correct choice, text boxes and video tutorials have been added to explain what the user had to do.

The app was constituted by two main Graphical User Interfaces (GUIs): 'select the day', and 'choice of the exercise'.

In the 'select the day' GUI, that is the home GUI, ten buttons representing the ten days of duration of the exercises and a help button were displayed at the bottom (Figure 2a). The button corresponding to the day of training that the user had to choose was highlighted; such button was the only one that triggered an event in the application allowing the user to proceed forward. For each day, the sequence of the exercises to perform has been defined by physiotherapists, and the number of the exercises was always ten.

Pressing the help button caused the playing of a tutorial video explaining to the user how to hold the tablet and how to perform the exercises. All videos in Bal-App had been recorded at I.R.C.C.S. Istituto Auxologico Italiano using a 360° camera (Ricoh Theta S). Instead, if the user tapped on the correct day button (that must be selected according to the number displayed and day-by-day), the 'choose the type of exercise' GUI was shown (Figure 2b). On this GUI, two buttons were displayed: the first one allowed the start of the *balance exercises*, while the second button initiated the *virtual riding*. Even in this case, just one button at a time was active and highlighted, and a written text explained to the user how to proceed forward.

To start an exercise session, the first button to tap was "start balance exercises". Only when balance exercises were completed, the virtual riding button becomes interactable.

Before the beginning of each exercise, either the balance exercises or the virtual riding, a GUI explaining how to set up the room where the user would perform the exercise, as well as how the tablet had to be placed or hold during the training, was shown (*Instruction GUI*) (Figure 2c). To go on with the exercise, the user had to tap on the start button at the bottom of the screen. To ensure that the user had correctly understood the exercise protocols, written instructions appeared in bright colours on a black background for five seconds before starting (*Reminder GUI*), and then an instructional video was played. In this video, a physiotherapist explained how to perform the exercise along with visual demonstration. At the end of the explanation, the user had to perform the exercise.

Once the user has completed the balance exercises, the application automatically returned to the 'choice of the exercise' GUI. At this point, the button to start the virtual riding was highlighted, and the *Instruction GUI* with the explanation of how to proceed forward was displayed. As for balance exercises, tapping on the start button caused a GUI with the instructions about the room setup and the performance of the exercise to appear.

The user's point-of-view in the virtual park flowed at a constant speed, as the person was actually riding the bike to proceed forward. During the cycling, objects with different colours appeared at the side of the pathway, and the user was asked to tap on only some of them, namely the ones coloured with the target colour. Depending on the day, the target

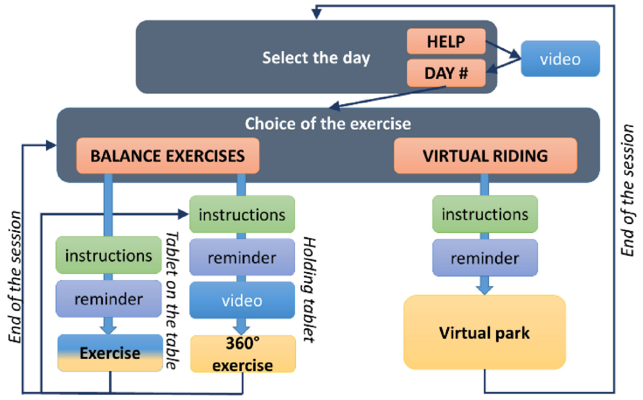


FIGURE 1 **Flow of the Bal-App application.**

colour was different: this information was communicated to the elderly prior to the beginning of the exercise, together with the other instructions. If the user tapped on an object of the right colour, a positive sound feedback was given, and the object colour changed to bright green; if the user committed an error, negative sound was played, and the object became red. The exercise duration was set to fifteen minutes. At the end of the time, the application returned to the 'select the day' GUI, and the user could quit Bal-App.

### B. APPLICATION ARCHITECTURE

The application has been developed using Unity3D. The behaviour of the application is driven by four scripts: DateCompare (DC), ManagerVideo (MV), Manager360 (M360) and ManagerPark (MP). The scripts written in Unity3D, define how the objects– such as GUI elements, 3D models, etc – behave. The programming language used to write the scripts within the Unity is C#.

DC script is launched at the start of the application. This script retrieves the date from the device where the application is running on and compares it with the date saved inside the application. On the first launch of the application, no date is saved, thus the application starts from day #1. If the saved date and the date retrieved from the device are different, the next day would be highlighted in the 'select the day' screen. Once all the ten days have been highlighted, a password is requested in order to start again from day #1. DC script also assigns the colour target that will be used in the 'virtual riding' scenario for each day.

Once the application is launched, the MV and DC scripts are invoked. MV script controls all the elements composing the GUI of the application, manages the sequence of the exercises to perform on a specific day and their respective videos, and activates M360 and MP upon request. After the day number (#) has been received from DC, the sequence of the exercises and the corresponding video to show, as well as the type of *Instructions* and *Reminder GUI*, are loaded from the local repository. The *Instruction GUI* is displayed once, at the beginning of the exercise session, while the *Reminder GUI* is shown before playing any videos (i.e., before the performance of each exercise). Each time a video has reached

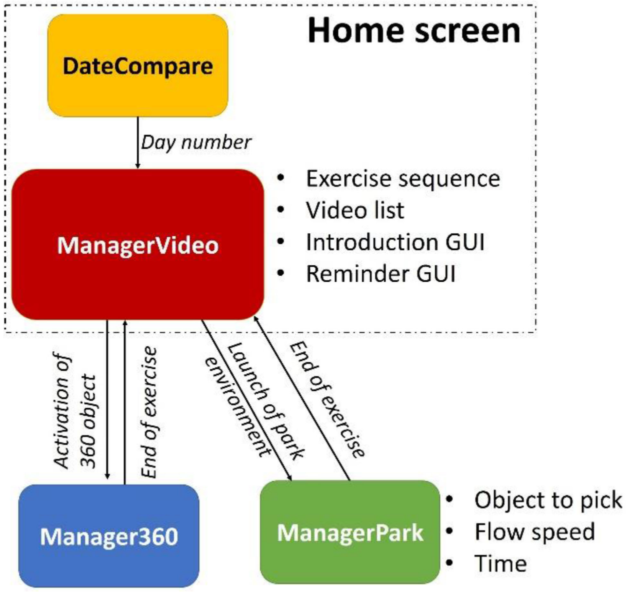


FIGURE 2. **A schema representing Bal-App architecture.**

the end, an event is triggered in order to load the next exercise. When the next exercise corresponds to a 360° task, the MV invokes the M360 script. When all the exercises are completed, the MV activates the MP.

The M360 script manages all the actions needed to perform the 360° exercise. To display a 360° environment in the application, a 3D model of a sphere with inverted normal is activated (i.e., it becomes visible in the device); the 360° image or video related to the task to perform, is then assigned to the sphere as a texture. To allow the rotation of the camera in the virtual scene (i.e., to the user's point-of-view), in order to explore the 360° environment, the XRSettings mode is switched from 'none' to 'CardBoard'. XRSettings are a set of options provided by Unity to natively activate the CardBoard Software Development Kit (SDK). Such SDK allows rotating the camera created in Unity3D, that is usually static, by using the data collected from the gyroscope and the accelerometer of the device; in this way, the user can freely look around the virtual world. Moreover, to interact with the objects placed in the scene in the different exercises, gaze control is activated. In fact, for each exercise a set of 3D models and GUI elements are placed in the scene: their position depends on the task requested by the exercise. The GUI elements are used to show the elapsing time, the number of objects still to be picked, and suggestions on how to perform the task. Once the user has completed the exercise or the time has run out, an event is sent to MV so that it can proceed forward with the next step (i.e., start a new exercise or return to the 'choice of exercise' GUI).

When all the exercises have been completed, MV triggers the display of *Instruction GUI* for the virtual riding task. Tapping on the start button, MP loads the virtual park environment. In this scenario, MP also manages the elapsing time, the creation of targets and of distractors on the side of the path, the user interaction with the device to choose the target objects and the respective feedback.

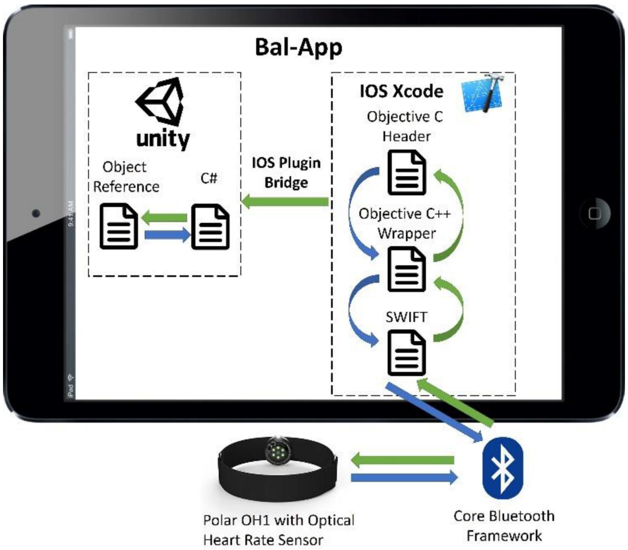


**FIGURE 3. Overall architecture of the iOS native plugin which bridges the gap between Unity application and Xcode.**

An Apple framework called Core Bluetooth was employed in order to retrieve the data from Bluetooth sensors (i.e., heart rate and cadence sensors) and to exploit it within iOS applications. However, this framework can be used only within the Xcode environment and utilized with Swift or Objective C programming languages. As a result, a native plugin needed to be implemented in Unity to bridge the gap between the Unity application and Xcode Bluetooth framework. In Bal-App case, a Swift code has been written exploiting the Core Bluetooth framework to fetch the information from Bluetooth sensor by collecting data from nearby Bluetooth peripherals over Bluetooth Low Energy (BLE) wireless technology. Each peripheral (Bluetooth sensor) exploits specific Bluetooth protocol which may contain multiple services and characteristics. This Swift code is responsible to access the Bluetooth peripheral, retrieve the data, and translate the hexadecimal data block into the human readable number.

An iOS native plugin also needed to be developed to make the Unity application access the information in the Swift code. For this reason, a C# script within the Unity Bal-App application is written. Such a script instantiates a Unity object as a reference point for calling the Swift code and receiving the parameters. In order for Unity's C# script to call Swift code, it is necessary to mark all the variables in the Swift code as 'public' (i.e., accessible from all the other objects).

Therefore, as shown in Figure 3, Xcode compiles an Objective-C generated header file behind the scenes, that can be used in the Objective C++ wrapper which calls the Swift functions. An Objective C++ wrapper was written to allow Unity to communicate directly with it, because Unity C# script is unable to communicate with Swift. The Objective C++ wrapper is responsible for listening to the requests coming from Unity and forwarding them to the Swift file. In order to invoke the Swift code to send the sensor information to Unity application, the system benefits from delegates. As a result, Unity was made able to observe the call-back data coming from Xcode by subscribing to these delegates.

### C. TASKS

The training program was based on a previous motor protocol for improving balance in frail elderly patients [37]; exercises were adapted to the devices employed in the present study. The proposed exercises were selected among those included in the daily clinical practice, in order to guarantee continuity with the control group as well. These exercises intended to stimulate balance reactions in patients by integrating all the proprioceptive and vestibular postural control systems with the aim of improving performance in daily life. The training program was built by selecting the most appropriate exercises for the domestic rehabilitation: this context necessarily entails this adaptation, in order to ensure patient safety.

Patients were trained for 10 days, 3 times a week through balance and bike exercises for about 30 minutes per session. Balance exercises encompassed two types of modalities: placing the tablet on the table (1) or holding the tablet (2). In the first case (1), the explanation video continued and showed a physiotherapist performing the task: the user was asked to mirror the movements and the activities in the video. In case (2), the user must face with a 360° exercise. In these exercises, the user was required to explore a 360° image or video with the aim of integrating the motor and cognitive exercises in a dual task and enhancing the effect of motor training. All the tasks are described below. For the first six days, only one 360° exercise was administered, while from day #7 to day #10, the 360° tasks increased to three.

To ensure patients safety, they were instructed to set up the room appropriately before starting a new session, (e.g., creating a space with no carpets, domestic animals, canes) and to wear appropriate, comfortable shoes. The exercises performed by patients were progressively more difficult throughout the sessions, to increasingly stimulate proprioception. Patients were also instructed to perform the exercises in favorable psychophysical conditions and to adjust the exercise difficulty whenever they felt unsafe performing them (e.g., with eyes closed or on one leg).

Specifically, the exercises of the first 3 days consisted in walking, alternating steps in space (anterior-posterior and lateral), moving load from one limb to another, maintaining the monopodial station, performing squat, climbing on tiptoe, doing rotations and flexion-extension of the head and trunk, placing feet in tandem position, and moving the load from a seated position. Patients were facilitated by executing the exercises with eyes open or by placing one hand on a support (e.g., on a table).

On days #4-#5-#6, patients were asked to perform the basic exercises, if possible, with closed eyes (visual deprivation) or with reduced support base (e.g., with no hands on the table). Moreover, the speed and the number of repetitions of each exercise were increased.

Days #7 to #10 included both a selection of exercises from days #4-#5-#6, and exercises holding the tablet, using the

360° function. These exercises consisted in achieving specific goals by exploring the virtual room represented in the tablet.

In the virtual riding scenario, the user had to pedal on the cycle ergometer while a virtual park was displayed on the tablet. The information regarding the user's HR, speed, and cadence were also displayed at the corner of the GUI on which the virtual park was shown – in case one or two Bluetooth devices were connected to the Bal-App. Indeed, this data could be retrieved from Bluetooth sensors worn by the users (for HR) and attached to the cycle ergometer (for speed and cadence).

## III. USABILITY TEST

### A. BACKGROUND

Usability is an important aspect of the interaction with the technology that should be analyzed whenever a new tool is developed. It could be defined as the degree to which a specific subject is able to use a given system to achieve specific goals effectively, efficiently and satisfactorily within a well-defined context of use [38]. More specifically:

- Effectiveness is the possibility for the users to achieve goals,
- Efficiency refers to the effort made by the users to reach the goal,
- Satisfaction is what users think about the interaction with the system.

In the present study, a formative evaluation was carried out using two instruments: The System Usability Scale (SUS) [38], [39], and a formative evaluation, carried out through a semi-structured interview. SUS is a "quick and easy to use" questionnaire composed by ten items, created by Brooke in the 1996 [38].

The final score can range from 0, lack of usability, to 100, optimal usability. The qualitative interpretation of the score was developed by Bangor and colleagues [39].

The aim of these "expert evaluations" was to collect information about the usability and interaction from the point of view of the final users. The interview focused on four primary areas: (1) use of the tablet; (2) main pages; (3) understanding of the instructions; (4) Exercises. For each of these topics minor themes were identified:

(1) Use of the tablet:
   - Switch on,
   - Switch off,
   - App shutdown,

(2) Main page:
   - Navigation,

(3) Understanding of the instructions:
   - Listening,
   - Comprehension,
   - Device interaction,

(4) Exercises:
   - Listening,
   - Comprehension,
   - Device interaction,
   - Executions.

**TABLE 1. Demographic data and SUS result's.**

| Subjects | Sex | Age | Y.o.e. | S.U.S. |
|---|---|---|---|---|
| 1 | M | 94 | 18 | 57,50 |
| 2 | F | 78 | 22 | 90,00 |
| 3 | F | 77 | 13 | 80,00 |
| 4 | F | 65 | 13 | 87,50 |
| 5 | M | 74 | 11 | 100,00 |
| 6 | F | 84 | 13 | 57,50 |
| 7 | F | 69 | 18 | 97,50 |
| **Mean** | | 77,29 | 15,43 | 81,43 |
| **S.D.** | | 9,62 | 3,95 | 17,61 |

*y.o.e.: year of education, S.U.S.: System Usability Scale, S.D.: Standard Deviation.*

The outcome is a description of the main difficulties emerged from the user interaction, the impact of the problem on the usability and the practical solutions. The results of the analysis could be used to refine the interaction design.

### B. PROTOCOL

For the assessment of the usability of our application we proposed 2 trainings: one before day #1 to introduce patients to the application and the second one between day #7 to #10.

The exercise session started with 15 minutes of balance training with and without 360° video, followed by 15 minutes of dual-task session. The exercises that exploited 360° videos were the following:

Exercise 1: while keeping arms extended forward, the patient was asked to march on the spot lifting knees high, performing 3 complete rotations to the right and 3 complete rotations to the left, reading the instructions on the screen.

Exercise 2: while keeping arms extended forward, the patient had to identify the two-colored bands placed on the ceiling and on the floor, performing flexion-extensions of the arms, head and trunk for 5 repetitions.

Exercise 3: while keeping arms extended forward, the patient had to search into the virtual room for 9 green-colored balloons by pointing them with the viewfinder in the center of the screen. Once identified, the balloons disappeared; on the screen there was also the count of the missing balloons.

Exercise 4: while keeping arms extended forward, the patient had to identify the colored balloons into the virtual room with the letters on them to compose the word "UNIVERSO". The letters had to be selected in the order in which they are present in the word, pointing the viewfinder at the balloon.

Exercise 5: while keeping arms extended forward, the patient had to identify the drone present at one point in the virtual room and, after take-off, he/she had to follow the aircraft while moving around the room pointing it with the viewfinder, until it landed.

### C. SAMPLE

A sample of 7 frailty patients was selected at the I.R.C.C.S. Istituto Auxologico Italiano. All the demographic information and SUS' scores are reported in Table I.

**TABLE 2. Qualitative usability results.**

| Tasks | Problem | Solutions | N.S. |
|---|---|---|---|
| **USE OF THE TABLET** | | | |
| **Switch on** | None | None | - |
| **Switch off** | Difficulty to find the tablet's "switch-off" button (mistaken for the camera) | Highlight the button on the back with stickers or colours | 3 |
| | Difficulty to remember the procedure; need for listening again to the instructions | Availability of a summary of the instructions | 1 |
| **App shutdown** | Need for the operator intervention | Availability of a summary of the instructions | 1 |
| **MAIN PAGE** | | | |
| **Navigation** | None | None | - |
| **INSTRUCTIONS** | | | |
| **Listening** | Instructions' speed | Improve the audio, adjusting the instructions' speed | 1 |
| | Excessive lenght | Provide more concise instructions | 2 |
| **Comprehension** | None | None | - |
| **Device interaction** | None | None | - |
| **BALANCE EXERCISE** | | | |
| **Listening** | Asks for confirmation to start the exercise | Encourage to listen carefully | 1 |
| | Starts the exercise during the explanation | | 1 |
| **Comprehension** | Difficulty due to excessive speed | Instructions' slowdown | 2 |
| | Would like to go back and listen to the instructions once more | Insert a button that allows to repeat the instructions once more | 1 |
| **Device interaction** | Does not understand the movements' direction, when the operator is placed frontally in the video | Demonstrate the exercise in the same position as the patients' one | 1 |
| **Execution** | Difficulty to keep the leg lifted while performing the exercise | Encourage the patient to execute the exercise as he/she can | 3 |
| | Need to keep the eyes open to avoid falling | Encourage the patient to keep his/her eyes open to avoid falling | 2 |
| **360° VIDEO - EXERCISE 1** | | | |
| **Listening** | None | None | - |
| **Comprehension** | Difficulty to understand and perform the task requested | Provide clearer instructions | 3 |
| | | Insert a first-person perspective in the instructions | |
| **Execution** | Dizziness | Provide slower execution of the exercise | 2 |

| | | | |
|---|---|---|---|
| **360° video – Exercise 2** | | | |
| **Listening** | None | None | - |
| **Comprehension** | Need for the operator's intervention to start the exercise | Provide clearer explanation of the exercise's starting point | 2 |
| **Execution** | None | None | - |
| **360° video – Exercise 3** | | | |
| **Listening** | None | None | - |
| **Comprehension** | Imitate the operator's behaviour, not understanding what to do | Insert a first-person perspective in the instructions | 1 |
| **Execution** | Complaint about upper limbs pain | Explicit the option to pause the exercise to rest in the instructions | 1 |
| **360° video – Exercise 4** | | | |
| **Listening** | None | None | - |
| **Comprehension** | Tries to touch the letters on the screen instead of aiming at them | Improve instructions' clarity | 1 |
| | Unsure if he has to follow the letters' order | | 1 |
| **Execution** | Complaint about upper limbs pain | Explicit the option to pause the exercise to rest in the instructions | 1 |
| | Dizziness | Slow down the exercise execution | 1 |
| **360° video – Exercise 5** | | | |
| **Listening** | None | None | - |
| **Comprehension** | Need for the operator's intervention to start the exercise | Improve instructions' clarity | 5 |
| | Confuses virtual environment with real environment | | 1 |
| **Execution** | Complaint about upper limbs pain, fatigued when he/she had to keep the arms raised | Explicit the option to pause the exercise to rest in the instructions | 1 |
| | Difficulty to aim at the drone | Slow the exercise's execution | 2 |
| **Dual-Task Training** | | | |
| **Listening** | None | None | - |
| **Comprehension** | Need for the operator's intervention to start the exercise | Improve instructions' clarity | 1 |
| **Device interaction** | Impossibility to pause the app | Add the option to pause | 1 |
| **Execution** | Cyclette's slipping | Improve the non-slip system on the cyclette | 3 |
| | Difficulty to correctly place the cyclette | | 3 |

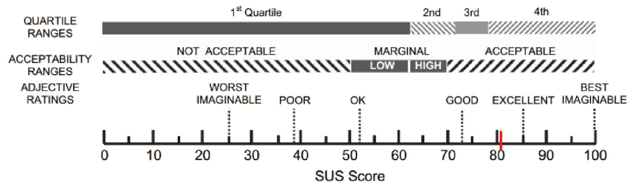


**FIGURE 4.** **Graphical representation of the interpretation of SUS.**

All patients signed the informed consent before being enrolled for the study.

### D. RESULTS

The mean score of the SUS was 81,43 (SD = 17,61). According to Bangor and colleagues [39] this score indicates an excellent level of usability of Bal-App application, as showed in Figure 4.

From the semi structured interview several interesting results emerged. Table II presents all the results: in the first column there is the description of the task analyzed; in the second the description of the encountered problem; in the third, there are some possible solutions to the identified criticality, and, in the last, there is the number of subject that reported those issues. The most problematic exercise is the one with the drone (Exercise 5). Patients reported difficulties in finding the drone before the start, and in following its trajectory because it was not completely linear. To solve this problem, we will modify the environment to facilitate the finding of the drone and we will try to make the instructions clearer. Also, in the exercise 1 patients reported some issues in understanding the task, and in continuing to rotate in the correct direction for all the time requested. To improve the understanding, we will insert the word "turn right" (or left) throughout the time.

Most of the other identified issues were linked to the difficulty in understanding the instructions, and the way to perform correctly the task proposed.

No problems concerning the use of 360° video (e.g., cybersickness) emerged during the sessions with patients.

To successfully allow patients to pursue the rehabilitation at home after the dismissal, they will be trained in using the application during the last clinical session. Specifically, a health professional (e.g., a physiotherapist) will show and explain all type of tasks, clarifying all the patients' doubts.

## IV. DISCUSSION

An innovative tablet-based application with 360° videos for the motor rehabilitation of frail elderly has been shown. The possibility to implement balance exercise at home safely and to exploit the potentiality of 360° videos has been explored for the first time, despite few tablet-based rehabilitative protocols presented in literature. The idea of this application was born from a desire of patients to have a guide that allows them to do the exercises correctly at home. After a period of in-hospital rehabilitation, physiotherapists usually suggest continuing the exercises at home. However, patients may have some difficulties to do the correct program at home by themselves and continue to do it for as long as necessary.

Our usability results are very promising, and we hope that the compliance with the treatment at home will be high to better understand if our motor rehabilitation program will be efficacious, even in comparison with the classical program.

Patients that took part in this study were very satisfied about the application and they expressed interest in having it at home. They were fascinated by the use of the Ipad to explore the virtual environment, reporting enjoyment in performing classical exercises in this innovative way. These tools will be powerful also for the dual task paradigm (motor and cognitive tasks) that could be crucial for the cognitive aspects of the rehabilitation programs.

In the future, a synchronized pedal-system will be implemented within the dual-task exercise (*virtual riding* scenario) to improve the realism and the sense of presence of the patients in the virtual environment. According to our usability results, it will be possible to develop several other applications based on this technology for elderly rehabilitation. Moreover, usability results could eventually allow us to make Bal-App available on an online store (e.g., PlayStore) and to make it accessible to the whole population as well.

## V. CONCLUSIONS

The goal of the present study is to assess the usability of a home-based rehabilitation treatment that ensures continuity with the in-hospital rehabilitation, without the direct supervision of the therapist: Bal-App represents a first important step toward this direction. We will provide a remote assistance for all the problems that could arise at home from the patients.

To evaluate the efficacy of the motor rehabilitation program (compared to the classic rehabilitation) this application will be included in a clinical trial for the motor rehabilitation of frail patients, exploring the potentialities of home-based training. This part will be a complementary treatment to the high-end part that patients underwent at the hospital using a fully-immersive technology, i.e., the Cave Automatic Virtual Environment (CAVE) [37].

## ACKNOWLEDGMENTS

This work was supported by the Italian funded project "High-end and Low-End Virtual Reality Systems for the Rehabilitation of Frailty in the Elderly" (PE-2013-02355948).

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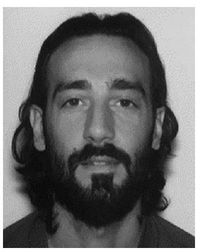

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