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FIT4MEDROB

D7.4.1

EXERGAMES AND AR/VR/MR EXERCISES #1

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DISSEMINATION LEVEL OF DELIVERABLE		
PU	Public, fully open, e.g. web	X
CO	Confidential, restricted under conditions set out in Partners Agreement	

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History of Changes

VERSION	SUBMISSION DATE	CHANGES
1.0	31/05/2024	First release
1.1	20/09/2024	Revised executive summary following external reviewers' suggestions.

TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

This Deliverable describes the state of the Fit4MedRob project regarding the development of Exergames (EGs) and serious games (SGs) based on Virtual, Augmented, and Mixed Reality Technologies (VR/AR/MR).

This Deliverable is a follow-up of Deliverable D7.4, submitted in Month 12.

We refer to the previous Deliverable D7.4 for the description of the VR/AR/MR technologies available in the Matchmaking activities.

In this Deliverable, we describe the status of the EGs and SG specifically developed in the context of Activity 7 to support the explanatory trials designed and planned within Activities 5-6 (available in D5.2.1-D5.3.1-D5.3.0-D6.3.0)**.**

The completion rate of this task is **100% in line with the foreseen plan,** as described in the following chart. The EGs and SGs will be released and made available for the trials with no foreseen delays.
One of the aims of the Fit4MedRob project, in particular of Activity 7, is to develop software solutions, also regarding serious games and exergames, that should be based on standard protocols rather than specific, ad hoc solutions.
As discussed in Deliverable D7.1, several different solutions exist to deliver immersive (or not immersive) VR content to the users, to track them inside a VR environment, and to collect and store data. Each contribution in this Deliverable is described, focusing on the Technical Specifications (referring to the framework described in D7.1), the specific use in Fit4MedRob (i.e., in one of the activities devised in the MatchMaking), the list of changes till Month 18, and a short description of the EG/SG.

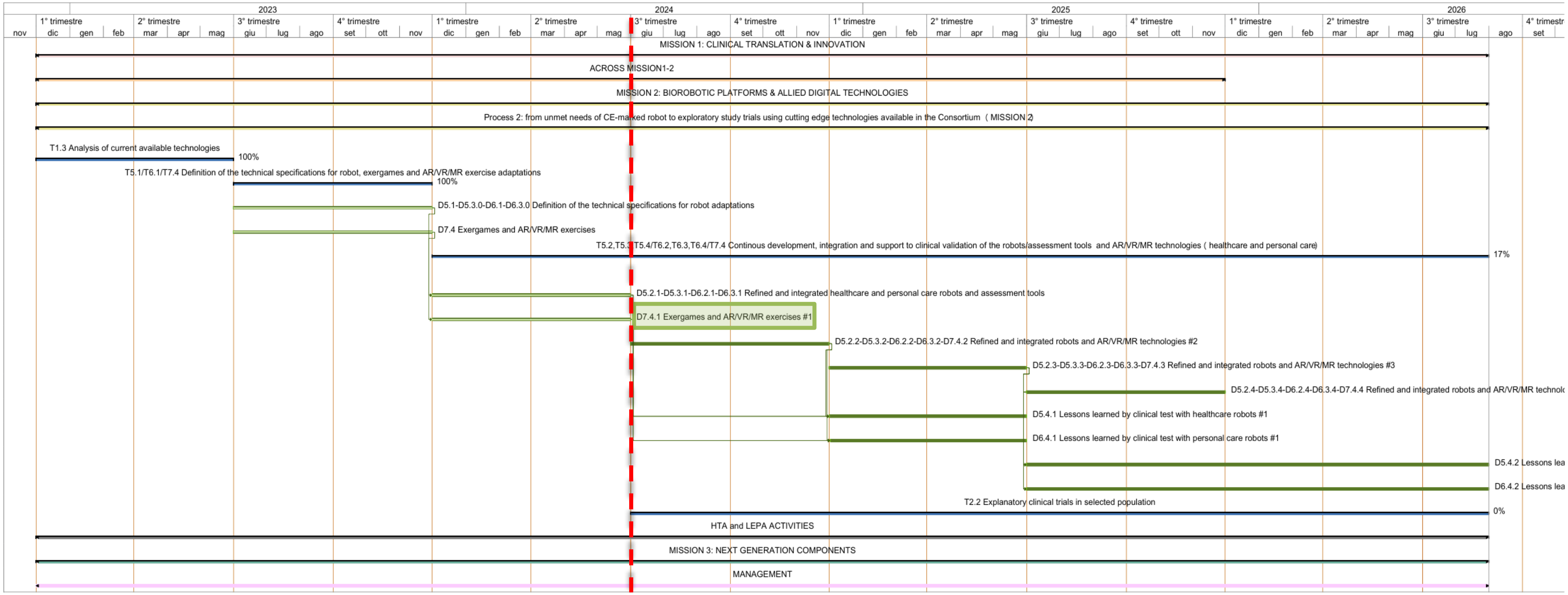
Each contribution has been summarized in a descriptive sheet, the structure of which is described in Section 3.

It is worth mentioning that within Fit4MedRob Mission 1 and 2, the development of EGs and SGs has followed different paths.

1. Some EGs and SGs were developed outside Activity 7. They were developed and implemented by the same research units that developed the robot infrastructure (mostly in Activity 5 and 6). Most of them existed before the start of the project, and their features fit the needs of the robots for which they were designed. The state of the art of these systems has been described in D7.4 (M12).
2. Some EGs and SGs are part of the platforms of the commercial robots used in Fit4MedRob. This is the case with the suite provided by Technobody, inside the products *Homing* and *D-wall*. A description of such exergames has already been provided in D7.4. At the moment, no changes from the industrial partner have been planned. Future changes and specific developments to cope with the needs of Fit4MedRob project will be reported in future deliverables.
3. Some EGs and SGs have been specifically designed and implemented within Activity 7 to support Mission 1 and Mission 2 activities. In such a case EGs and SGs have been developed to support an existing robotic platform to specifically address the needs of the trials.

This deliverable focuses on the third category of exergames and serious games. In particular, here, we will report the advancements relative to:

1. Integration of the robotic platform with the software, specifically to use the data collected from the robot to control the game.
2. Design of the game: user interface for both the patient and the therapist, configuration parameters, gamification, and design choices to balance the therapeutical outcome and the patient’s engagement.


2023
2024
2025
2026
MISSION 1: CLINICAL TRANSLATION & INNOVATION
ACROSS MISSION1-2
MISSION 2: BIOROBOTIC PLATFORMS & ALLIED DIGITAL TECHNOLOGIES
Process 2: from unmet needs of CE-marked robot to exploratory study trials using cutting edge technologies available in the Consortium (MISSION 2)
T1.3 Analysis of current available technologies
100%
T5.1/T6.1/T7.4 Definition of the technical specifications for robot, exergames and AR/VR/MR exercise adaptations
100%
D5.1-D5.3.0-D6.1-D6.3.0 Definition of the technical specifications for robot adaptations
D7.4 Exergames and AR/VR/MR exercises
T5.2,T5.3,T5.4/T6.2,T6.3,T6.4/T7.4 Continous development, integration and support to clinical validation of the robots/assessment tools and AR/VR/MR technologies (healthcare and personal care)
17%
D5.2.1-D5.3.1-D6.2.1-D6.3.1 Refined and integrated healthcare and personal care robots and assessment tools
D7.4.1 Exergames and AR/VR/MR exercises #1
D5.2.2-D5.3.2-D6.2.2-D6.3.2-D7.4.2 Refined and integrated robots and AR/VR/MR technologies #2
D5.2.3-D5.3.3-D6.2.3-D6.3.3-D7.4.3 Refined and integrated robots and AR/VR/MR technologies #3
D5.2.4-D5.3.4-D6.2.4-D6.3.4-D7.4.4 Refined and integrated robots and AR/VR/MR technolo
D5.4.1 Lessons learned by clinical test with healthcare robots #1
D6.4.1 Lessons learned by clinical test with personal care robots #1
D5.4.2 Lessons lea
D6.4.2 Lessons lea
T2.2 Explanatory clinical trials in selected population
0%
HTA and LEPA ACTIVITIES
MISSION 3: NEXT GENERATION COMPONENTS
MANAGEMENT

2. DESCRIPTIVE SHEET FOR EACH EXERGAME/SERIOUS GAME

According to what we described in D7.1 and D7.4, one of the aims of Activity 7 is also to define a coherent framework to describe the various components of the systems and, in particular, their interconnections and how data are collected and exchanged. Specifically, as the development of systems based on VR and AR are concerned, we described the state of the art of the available technologies and methods.
In order to be coherent with the previous descriptions, we summarize the main features of the available technologies, as described in the following.
Below each entry of this descriptive sheet, a short explanation is provided, in order to clarify the meaning of the technologies/solutions, especially in the context of the Fit4MedRob project.

Description #NAME

Category: Exergame or Serious game

Reference person(s) for software design and development: (here indicate the list of people and their affiliations)

Other personnel/groups involved in the design: (here indicate the list of people and their affiliations)

Development Platform and other external assets/libraries: provide version details and/or useful links

Technical Specification

PC-based/Standalone: a standalone device could be convenient regarding portability and costs; conversely, it could limit real-time monitoring and modifications (e.g., mirroring could not always be stable). PC-based systems, though more expensive and complex in terms of setup, allow more displays to be connected. Therefore, the therapist could interact with the VR training scenario during the live session.

Visualization Devices: VR - fully immersive/semi-immersive/non-immersive AR - tablet/Monitor - VST/OST

Considering the level of immersion, VR and AR environments can be characterized by (i) the level of immersion described with respect to the used devices for visualization and (ii) the coexistence of real and virtual elements.

Considering the level of immersion in **VR**, i.e., the systems where users act in a completely computer-generated environment, the following visualization methods are possible:

- **Fully immersive** VR systems in which the user is completely isolated from the external (real) world. In such systems, the sight of the surrounding environments is hampered by a head-mounted display (HMD). Typically, other senses are hidden, e.g., sounds and noise from the real world are substituted by sounds played in VR. Several commercial immersive VR devices are available: HTC Vive Pro Series, or Meta Oculus devices.
- **Semi-immersive VR** systems, in which the user is in front of one or several “standard” displays. Systems in this category may be composed of a single large display or projector, or a large, curved display (ideally occupying all the visual field of the patient). In other configurations, several “standard” monitors are arranged in a multi-monitor configuration to extend the field of view. In this configuration, they partially hide the surrounding real environment. Such systems are widely used in simulation scenarios. Usually, visualization is not stereoscopic, thus hampering the correct estimation of the depth of virtual elements. Stereoscopic visualization is possible only with specific systems, e.g., the CAVE [2].
- **Non-immersive** VR systems, in which the user is in front of a standard display (e.g., PC monitor or a smartphone/tablet). Though the level of immersion, thus the sense of presence, cannot be like that of immersive VR systems, they are the most common and flexible solutions.

Considering **AR**, devices can be divided into two main categories:

- **Video see-through (VST)**, where a standard camera captures the real environment, and an augmented visualization is obtained by combining the camera feed and a computer-generated image. Typically, VST systems are based on standard smartphones and tablets, though recent HMD devices are based on this technology, such as Meta Quest3 and Apple Vision Pro.

- **Optical see-through (OST)**, where an optical combiner allows the user to see both the real environment and computer-generated images reflected on it. Several commercial devices using this technology exist, e.g., the Microsoft HoloLens.

Visualization Devices (HW): if available, indicate the hardware (producer, model, version)

Interaction devices: controllers/standard or depth cameras/IMUs/other devices/robots (provide accurate description)

The range of possible interaction modalities to act inside XR is wide. Among the off-the-shelf techniques, we could mention:

- using **controllers**, e.g., videogames pad, mouse, keyboard, or the controllers sold with the HMDs;
- tracking the user's movements with **non-wearable devices**, e.g., cameras (both standard or depth cameras), or with marker-based systems;
- using **gloves**, which also may provide tactile or force feedback.

In the specific context of rehabilitation, it is also worth mentioning the following interaction techniques:

- using **gaze**, exploiting the tracking systems embedded in some commercial HMDs or the tracking device that could be attached to any PC and positioned onto a monitor or TV. Such interaction technique is considered for people not able to use or control the upper limbs;
- using specific signals like **electromyography**, i.e., the technique for evaluating and recording the electrical activity produced by skeletal muscles;
- using **heart-rate** monitoring systems to know the stress state of the user, and eventually modulate the exercise, accordingly.
- The convergence of VR and emotion recognition tech (facial expressions), for the reason of understanding user reaction;
- using **robots** as interfaces between the patients and the digital contents, e.g., the exergames.

Interaction Devices (HW): if available, indicate the hardware (producer, model, version)

User Interfaces

In general, the EGs SGs should communicate input/output data with:

- the **therapist**, who could set up all the useful information of the patient, with the data coming from the patient's dashboard (see overall ICT architecture described in D7.1).

  In particular, the therapist will decide:

  - the list of exercises, number of repetitions, duration of the session for EGs;
  - the game levels, if the SG is structured into levels of different difficulties and he/she will have access to (some of this information may also be displayed in real-time during the exercise):
  - the outcome of the EGs and SGs, e.g., total score, number of completed levels
  - data recorded from the EGs and SGs, e.g., the patient's 3D joint position or summarized measurements as limb elevation
- the **patient**, who could benefit from doing exercises in VR/AR/MR through the possibility of customizing the environment. In particular, he/she could choose:
  - the virtual environment where the training session will take place;
  - the aspect of the agents (self-avatar or other agents with whom to interact);
  - the actual games to be played, if a choice is available.

Of course, the list of input/output depends on the specific exergame; thus, it is difficult to define a common input/output interface. The problem has been largely discussed in D7.1. During the development phase, standard interchange formats will be used to inject all the collected information into a unified data lake.

Therapist user interface: describe the parameters the therapist can set up and the output data he/she will see during and after the training session. If available, provide snapshots of the user interface.

Patient user interface: describe the parameters that can be set up by the patient and the output data he/she will see during and after the training session. If available, provide snapshots of the user interface.

3. VirtualAvatars4Rehab

VirtualAvatars4Rehab is an immersive VR system, where the user/patient, wearing an HMD could do physical exercises following the indication of a virtual therapist, i.e., an avatar animated with a set of prerecorded physical exercises.
VirtualAvatars4Rehab can be personalized both from the appearance point of view, i.e., the patient could customize the visual appearance of the environment or of the therapist, and from the therapeutic point of view. Indeed, the therapist can describe the list of exercises, setting durations, repetitions, and movement targets.
In Fit4MedRob, VirtualAvatrs4Rehab will be used for patients with **musculoskeletal disorders.** Musculoskeletal disorders are considered to be the leading worldwide cause of pain and physical impairment [3]. Among them, shoulder diseases are very frequent, and patients may experience several negative consequences, such as reduced range of motion, worse quality of life, and severe restrictions in performing activities of daily living, and work [4]. The rehabilitative process is crucial for the functional recovery of patients with shoulder musculoskeletal disorders [5]. In recent years, new rehabilitation protocols using different technologies have been developed. The combination of Virtual Reality (VR) and healthcare represents a relevant topic in scientific and clinical scenarios due to its potential to generate new products and services as adjuncts to the rehabilitative process, thus defining a new concept of patient care [6].
In the following, we provide the technical details and the description of VirtualAvatars4Rehab, the VR-based system developed in collaboration with Fondazione Policlinico Campus Biomedico Roma (Mission 1 - responsible person Prof. Giuseppe Umile Longo) for the physical exercise of patients with **shoulder musculoskeletal disorders**.

The VR system is based on a set of technologies already available at Unige - DIBRIS (Prof. Manuela Chessa), specifically adapted to meet the needs of the Fit4MedRob project and shoulder musculoskeletal disorders. **The technology is also described in the Deliverables of Activity 5 because the technology will be used in the Matchmaking A5# 46**

3.1 Descriptive Sheet

VirtualAvatars4Rehab

Status in Fit4MedRob: Full functionalities ready. Available for explanatory clinical trials Batch 2. Customization to meet the FPUCBM patients' needs is under development. Customization to meet the ICS Maugeri patients' needs is under development.

Category: Exergame

Reference person(s) for software design and development: Manuela Chessa (Unige), Giuseppe Umile Longo (FPUCBM), Giovanni D'Addio (ICS Maugeri)

Other personnel/groups involved in the design: Eros Viola, Andrea De Filippis (UniGe), Carla Antonacci, Arianna Carnevale, Matilde Mancuso (FPUCBM), Paola Baiardi, Christian Lunetta (ICS Maugeri)

Development Platform and other external assets/libraries: Unity3D 2023 LTS; XR Plugin Management (Version 4.4.0); OpenXR Plugin (Version 1.8.2); XR Interaction Toolkit (Version 2.5.2) with Starter Asset and Hands Interaction Demo Samples imported; XR Hands (Version 1.3.0) with the HandVisualizer Sample imported; Input System (Version 1.8.0-pre.2); FinalIK (Version 2.3); IMMERSE framework (Version 1.0)

Technical Specification

PC-based/Standalone: PC-based. In the actual implementation, the HMD is connected to a PC, where the therapist user interface is running. In a future implementation, we will develop the standalone version, controlled by a tablet.

Visualization Devices: fully immersive VR

Interaction devices: controllers of the headset and hand tracking provided by the headset

3.2 System description and development

Here, we will provide the details of the VR system and the associated exergame.

The system can be used with any immersive VR device; and proposes a set of rehabilitation exercises (taken from the list of exercises already used at FPUCBM Rome) to be performed in a completely VR setup.
The animation of the virtual therapist has been pre-recorded using a motion capture system. The system's user interface allows the patients to choose their own avatar's appearance, the aspect of the therapist, and the environment in which they can perform the exercise. The (real) therapist can configure the number of repetitions of each exercise, the resting phases, and the goal to be achieved in terms of angular limb position. The system can be used with the main off-the-shelf immersive VR system, i.e., the Meta Oculus Quest 2 or HTC Vive Pro. Inside the XR system, the patient could see a virtual avatar performing a set of exercises to be replicated. The users could personalize the visual aspect of their avatar, the visual aspect of the therapist's avatar, and the environment where to do the exercise, choosing each time a pleasant and enjoyable scenario. The therapist, considering the patient's previous history and training sessions, could personalize the list of exercises, the duration, and a set of goals to be achieved in terms of limb extension and joint angular positions. The system measures and records in real-time the movements of the patients, using the IMMERSE framework1 (details about the considered feature of the framework in Section 3.2.1).

In the current version of VirtualAvatars4Rehab, the exercise list has been pre-recorded using a Qualysis motion capture system and an animation file to animate the therapist's avatar. The following exercises (devised for shoulder musculoskeletal disorders) are currently available:

- Pendulum
- Upright active FE with no weight (FE)
- Standing dumbbell ER in the scapular plane
- Seated military press (Military Press)

For each of them, it is possible to configure:

- Number of repetitions
- Total duration of the exercise (time between repetitions)
- Expected ROM

In testing clinical centers where motion capture systems are available, it could be possible to record customised movements to be added to the library of exercises available in the application.

VirtualAvatars4Rehab is composed of two different User Interfaces (UIs):

- the *therapist view*, where the therapist (or the caregiver) could configure the exercise. This UI is in non-immersive visualization. In the current version, it is displayed on a standard PC/laptop. Further development may introduce a tablet visualization, but it is not a priority for the project;

- the *patient view*, which is in immersive VR (so inside the head-mounted display). Note that there is the possibility of bypassing the patient view and demanding the users' configuration from the therapist. This feature has been introduced to cope with possible patients who are hampered or not willing to proceed with any customization. In such a case, the patient will be directly "immersed" into the rehabilitation scenario without the need for any input from their side.

Figures 1, 2 and 3 show some panels in the *therapist view.* We have followed the guidelines adopted by Microsoft MRTK library to use fonts that are easily readable by everybody, and colors that should minimize eye strain and fatigue effects[2].

[1] E. Viola, M. Martini, F. Solari, M. Chessa. *IMMERSE: IMMersive Environment for Representing Self-avatar Easily.* IEEE GEM 2024
[2] https://learn.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk2/?view=mrtkunity-2022-05

Fig. 1 Screenshot of the initial panel in the therapist view.

Fig. 2 Screenshot of the panel of the therapist view, from which the therapist can access the patient data.

Fig. 3 A screenshot of the panel of the therapist's view shows the therapist's ability to configure the exercise. The panel is compliant with the protocol of the explanatory clinical trial carried out by FPUCBM in Matchmaking A5# 46.

Figures 4 and 5 show some panels in the *patient's view*. In this view, the patient could configure the visual aspect of his/her own avatar, the visual aspect of the therapist's avatar, and the environment where the exercises will take place.

To select the avatar and the environment the patient must use the controllers of the headset. Their use is intuitive and in several previous works, has been shown to be the preferred interaction modality [7] in immersive VR. In any case, the therapist can make the choice from his/her user interface.

Fig. 4 A screenshot of the panel of the patient's view, where it is possible to choose the visual aspect of the avatar.

Fig. 5 A screenshot of the panel of the patient's view, where it is possible to choose the environment where to perform the exercises.

The list of available avatars can be increased by everybody (also the user) just by putting in a dedicated folder a human rigged avatar.

The list of environments could be enhanced, too. In this case, it is necessary to validate the physical dimension of the created virtual environment and the design rules we have followed to create them. Adding a new environment cannot be done by the user, at the moment, though it can be easily done by a Unity developer.

Indeed, the virtual environment must have the following characteristics:

1. context information (background) must be present without disturbing the patient doing the exercise. So the place where the patient and the virtual therapist act is free from other objects, possibly capturing their attention (see Figure 6);
2. useful information for the patient (e.g., the elapsed time, or the ROM) is displayed by exploiting objects in the scene (see the clock in Figure 6);
3. scenes are quite rich in visual details, without excessively hampering the computational load.

Fig. 6 The beach environment (Left); The park environment (Right).

3.2.1 IMMERSE Framework

Immersive VR is typically experienced through head-mounted displays (HMDs) where interactive VEs are shown in 3D. Full-body representation in VR means adding to VEs an avatar representing the user's body, seen from his own perspective, thus mimicking what happens in our common real-world experience. The most used game engines for creating VEs are Unity3D [8] and Unreal Engine [9]. Both are multiplatform and support a wide range of HMDs and additional devices like the one typically used for user tracking. This support is either native or provided by installing additional plugins. Often, it is necessary to combine different sensors to overcome the limitations of the devices. For example, the Leap Motion was usually attached to an HMD to add hands-tracking functionalities to VR headsets, like the Oculus Rift [10]. Though nowadays many HMDs provide native hand-tracking solutions, many applications still rely on external tracking devices for their possible use in non-immersive contexts, especially in fields like the development of medical exergames [11], [12]. In other examples, researchers used depth cameras, like the Microsoft Kinect, to track the full body and insert it inside VR [13]. Other examples fused together body and hand tracking to achieve a complete user representation [14], [15].

Such solutions have been extensively discussed in the first phase of the projects and especially concerning the Matchmaking activity with FPUCBM. Though at the moment we have decided to focus on the Meta Oculus Quest devices, we aimed to develop VirtualAvatrs4Rehab easily usable with other HMDs or tracking devices. Also, the framework allows an easy switch between the standing and the sitting positions, which is a requirement if some of the patients are not able to stand for a long time.

To this aim, it is necessary to have solutions that easily allow developers to integrate sensors, head-mounted displays, and other tracking devices into the development environment. In the literature, there exist several tools trying to do this (refer to [16] for a review of this, highlighting strengths and weaknesses and motivating the need to have an easy and quick tool to cope with the issues).

We refer to [16] for the technical details about the framework, here we summarize the features used in the VirtualAvatars4Rehab VR setup:

1. Possibility of changing the chosen HMD (e.g., from Oculus Quest to HTC Vive).
2. Possibility of switching, also at run time, from the use of controllers to the hand tracking of the headset (necessary when asking the patient to lift up specific objects, like the stick).
3. Possibility of computing the 6DOF position and orientation of specific parts of the body, to be used: to assess the goal of the exercise (e.g., the desired ROM), to provide online feedback to the patient, and for further evaluation. Figure 7 shows for which point we can compute the 6DOF pose. It is worth noting that for the points actually

tracked, we have a direct estimation of the 6DOF pose, for the other point, we rely on the estimation of an Inverse Kinematic Solver (at the moment, FinalIK[3]). The robustness of the solution has been assessed for healthy subjects.

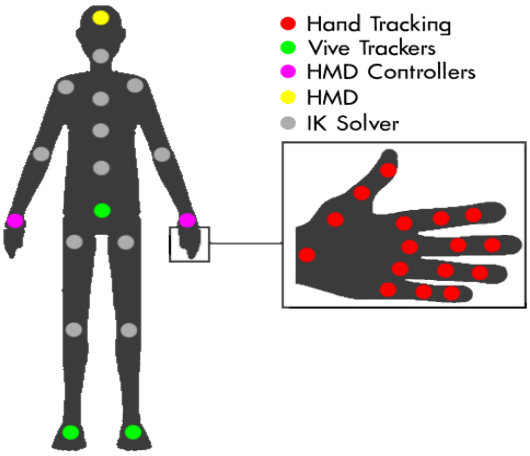


Fig. 7 Points on the patient for which we can compute or estimate the 6DOF.

Figure 8 shows the virtual therapist (the woman with the violet skirt) and the patient doing exercises in an environment resembling a gym. In such a case, a mirror is present, so the patient can see both the therapist's movements and his/her own actions (like in a real gym).

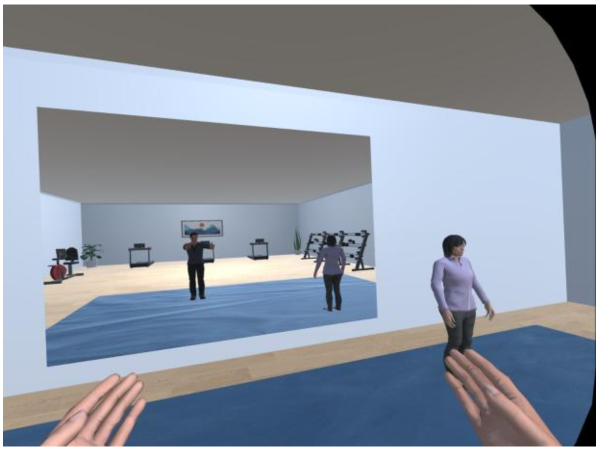


Fig. 8 A snapshot of VirtualAvatars4Rehab (seen from the patient's point of view) in a gym environment.

3.2.2 Future development

VirtualAvatars4Rehab may also be exploited in other clinical settings, to implement cognitive protocols.
In collaboration with ICS Maugeri, we are designing cognitive tasks that stimulate executive functions, visual exploration and attention, performed together with motor tasks in order to train patients on dual-task conditions. Motor performance for each patient was measured under two different conditions:

1) single task (only motor exercises);
2) motor-cognitive dual task (motor exercises performed together with cognitive tasks).

The list of cognitive tasks is reported behind:

[3] https://assetstore.unity.com/packages/tools/animation/final-ik-14290

· go/no-go punch game;
· go/no-go stepping game;
· number punch game;
· objects reaching with cognitive load and attentional interferences;

4. PLAYCUFF EXERGAME

4.1 DESCRIPTIVE SHEET

PlaycuffExergame

Status in Fit4MedRob: Integration with Playcuf device is ready. Exergame design and development ongoing.

Category: Exergame.

Reference person(s) for software design and development: Manuela Chessa (Unige) and Simone Pittaccio (CNR-ICMATE).

Other personnel/groups involved in the design: Marianna Pizzo (UniGe), Fabio Lazzari (CNR-ICMATE).

Development Platform and other external assets/libraries: Unity3D 2023 LTS.

Technical Specification

PC-based/Standalone: PC-based. The Playcuff device and the monitor are connected to a PC running the exergames.

Visualization Devices: non-immersive VR.

Interaction devices: Playcuff device developed by CNR-ICMATE (see deliverables of Activity 6).

4.2 SYSTEM DESCRIPTION AND DEVELOPMENT

The Playcuff device developed by CNR-ICMATE is a sensor-endowed orthosis for the upper limb in the shape of a soft wristband with embedded pseudoelastic springs that produce joint extension moments (see Figure 9). The device, designed specifically for the rehabilitation of children, has a dual function to deliver dynamic postural stabilisation of the wrist and hand and act as a wireless video game controller.

Fig. 9 The Playcuff device.

The wristband is available in different sizes, fit for children of different age groups. The intensity of the joint extension can also be personalised in order to optimize comfort, posture and avoid spasticity-related hyperreflexia. Alongside the sensors, Playcuff includes an onboard system for real-time recognition of multisegmental 3D gestures of the upper limb. Playcuff will be used to control a set of exergames specifically designed and implemented having in mind the following features:

- The interaction with the games is obtained through the gesture's classification from Playcuff. In particular, the following actions and gestures are currently classified (see Table 1).
- The gestures inside the game should not differ too much with respect to the actual movements performed by the patient and measured by Playcuff. This is necessary in order not to create confusion and perceptual

mismatch. As an example, an up/down movement along the vertical axis should not be mapped into a left/right movement inside the game.

- The set of exergames should accomplish both the task of allowing the patient to complete rehabilitation tasks and the goal of being engaging and amusing the patients, considering that the target population is composed of children and teenagers.

Table 1 Playcuff device gestures classification. The classification is the input of the exergame.

Code	Classification of static forearm
sO_P	Horizontal static forearm – pronated hand
sO_PN	Horizontal static forearm - hand at a 45° angle between pronated and neutral position
sO_N	Horizontal static forearm - neutral hand
sO_SN	Horizontal static forearm - hand at a 45° angle between supine and neutral position
sO_S	Horizontal static forearm - supine hand
sO_SM	Horizontal static forearm - hand at a 45° angle between supine and neutral position (Left-handed)
sO_M	neutral hand (Left-handed)
sO_PM	hand at a 45° angle between pronated and neutral position (Left-handed)
sD	static forearm downwards
sU	static forearm upwards
	Classification of moving forearm. Three tiers implemented (1 slow, 2 normal, 3 fast)
mU	Forearm horizontally extended, forearm moving upwards (up to 45° from the horizon)
mD	Forearm horizontally extended, forearm moving downwards (up to -45° from the horizon)
mR	Forearm horizontally extended, forearm moving downwards to the right
mL	Forearm horizontally extended, forearm moving downwards to the left
dU	Forearm upward extended, movement in all 4 directions (beyond 45° from the horizon)
dD	Forearm downward extended, movement in all 4 directions (beyond -45° from the horizon)
rA_CW	Supination: the forearm rotates clockwise (as to open a knob)
rA_CCW	Pronation: the forearm rotates counterclockwise
	Wrist classification: the wrist classification occurs simultaneously with that of the forearm
s	Static wrist
mF	wrist flexion
mE	Wrist extension

To address the previously mentioned aspects, the design and development phase of the Playcuff exergames has comprised the following steps.

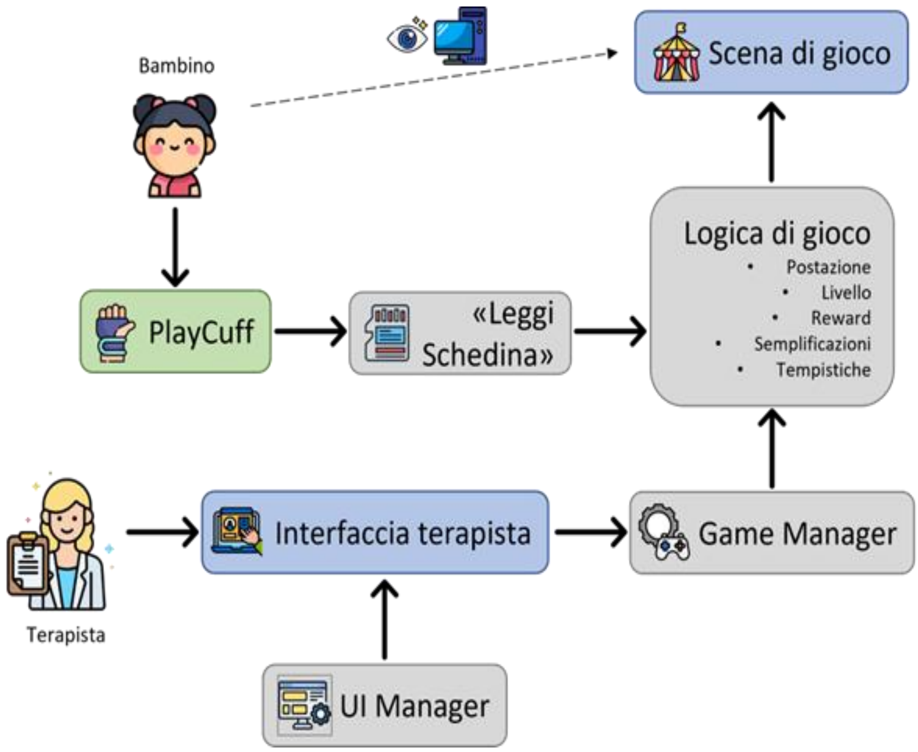


Fig. 10 Overview of the Playcuff exergame, comprising the interface with the Playcuff device and the therapist User Interface.

1. Integration of the Playcuff device into the Unity 3D environment (see Figure 10).
2. Creation of the first working prototype of the game, in the following referred to as “Il fiorista” (see Figures 11 and 12). The goal of the game is to take the flowers from the flowerpot.
3. Creation of a user interface for the therapist, where he/she could set all the parameters for the specific session and patient (see Figure 13).
4. Preliminary analysis of the interaction and the visualization modalities, to maintain an acceptable level of embodiment and self-agency, together with a pleasant visualization. Considering that the exergames should be visualized onto standard displays (non-immersive VR), the possible visualization solutions are: 1) 2D game; 2) 3D game and perspective visualization; 3) 3D game and orthographic visualization. In addition to the previous choices, it is possible to 1) visualize the arm/hands of the patients from a first-person point of view; 2) give a schematic representation of the hands like a pointer on the screen; 3) do not represent the arms/hands of the patient. The previous solutions are different in terms of perceived sense of presence in the game, agency, embodiment, and playability. A comprehensive analysis and comparison of the previous visualization modalities is ongoing (planned submission to IEEE ISMAR 2024).

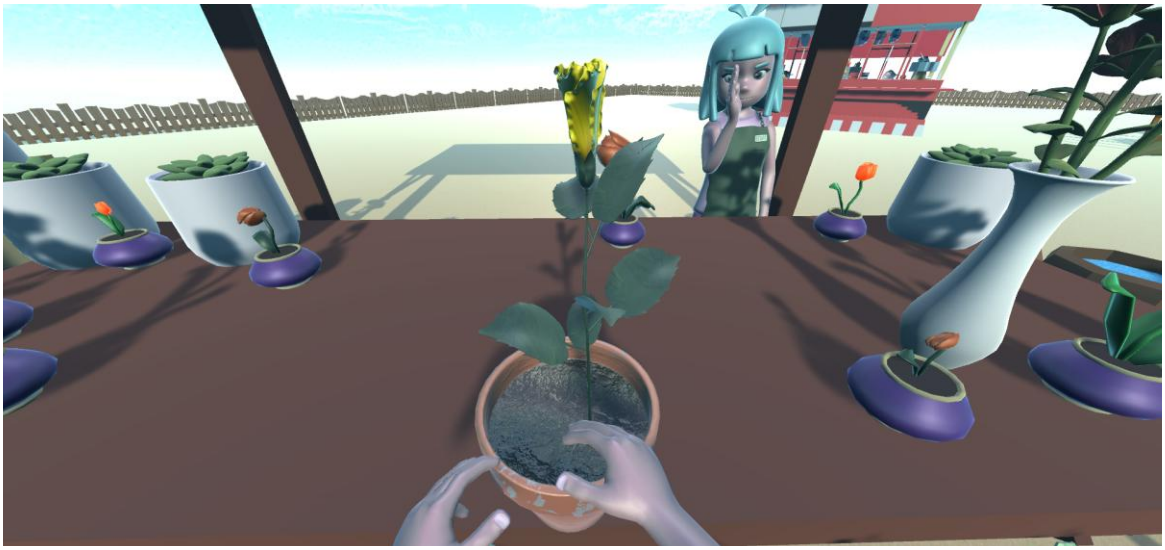


Fig. 11 Initial scene from “Il fiorista”, the first prototype developed to design the interface between the Playcuff device and the Unity3D gaming environment.

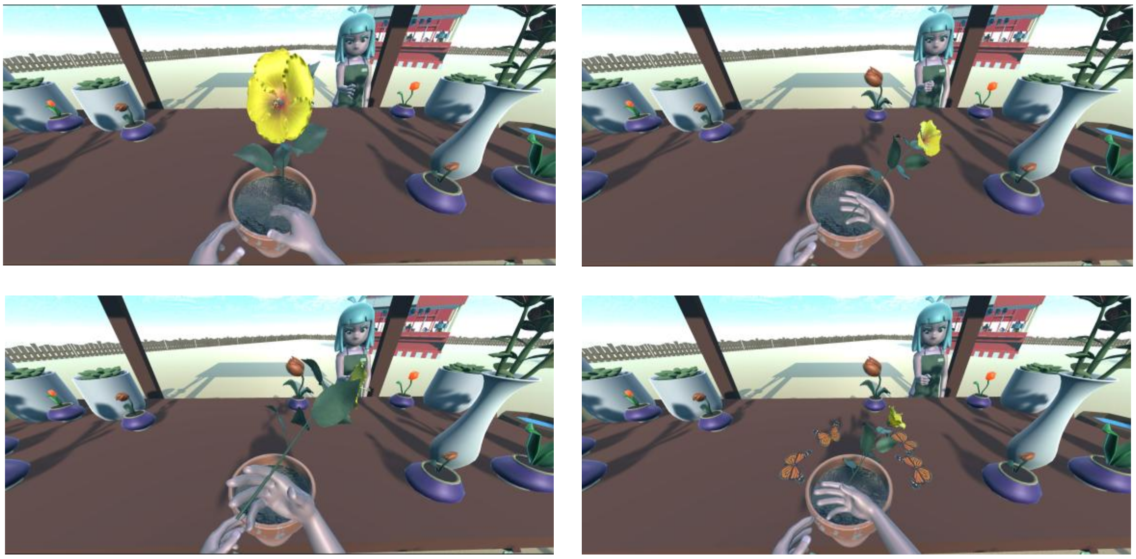


Fig. 12 Various scenes from “Il fiorista”. The last image shows the reward, which is fundamental to engaging people and giving them positive feedback about the right completion of the task.

Fig. 13 Therapist user interface to set the parameters for the specific patient (full details not yet available, because depending on the next steps).

A companion avatar is always available to show the correct movement to be performed (see Figure 14).

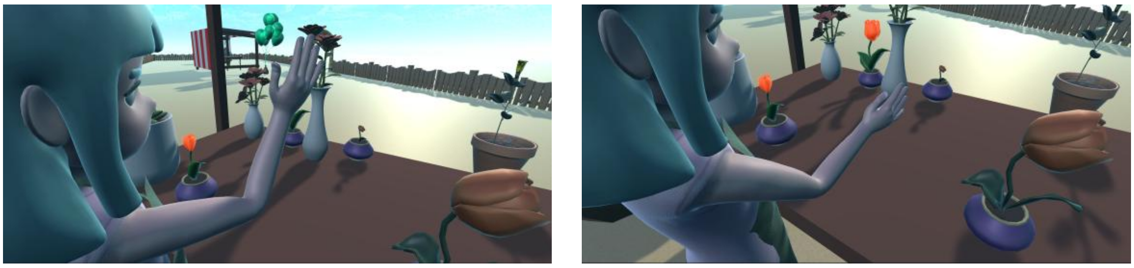


Fig. 14 The avatar girl is showing the patient the correct movement to be performed.

After a preliminary analysis, the following conclusions and next steps have been declined:

1. **The interface with the Playcuff device works correctly**, indeed it is possible to play with 'Il fiorista". We have not performed a detailed user study to evaluate the usability, demanding it to the complete exergame (see next steps).
2. Having focused more on the specific muscle activation and the precise movements to be performed, we believe that the current version of the game may not engage children and teenagers as expected.
3. For this reason, we are using the developed software environment to implemen**t a set of more engaging games inspired by sports activities**. Each game should ask for a specific arm movement: swing, prono supination, flexion-extension (see D5.2.1 D6.2.1 D5.3.1 D6.3.1 for a more detailed description of the Playcuff device and the supported and detected arm movements). This design phase is in collaboration with the Mission 1 partners who will use the device and the exergames.

5. Virtual Supermarket

5.1 Descriptive Sheet

VirtualSupermarket

Status in Fit4MedRob: The first prototype of the virtual environment is ready and has been tested in non-immersive virtualization. Ongoing: porting to immersive VR and gamification.

Category: Serious Game.

Reference person(s) for software design and development: Manuela Chessa (Unige), Giovanni D'Addio (ICS Maugeri).

Other personnel/groups involved in the design: Marianna Pizzo, Fabio Solari (UniGe), Paola Baiardi, Christian Lunetta (ICS Maugeri).

Development Platform and other external assets/libraries: Unity3D 2023 LTS.

Technical Specification

PC-based/Standalone: Not yet defined.

Visualization Devices: immersive VR.

Interaction devices: Controllers or camera tracking of the devices

5.2 System description and development

The system is based on the VirtualSupermarket presented and validated in [7] and [17] for assessing the cognitive status of elderly people.
The VirtualSupermarket is a serious game inspired by the common actions of going to the supermarket, reading a list of items to buy, finding the items on the shelves of the supermarket, putting them in the basket, and eventually removing them (see Figure 15 left) and finally going to the cash desk and pay the correct amount of money (see Figure 15 right).

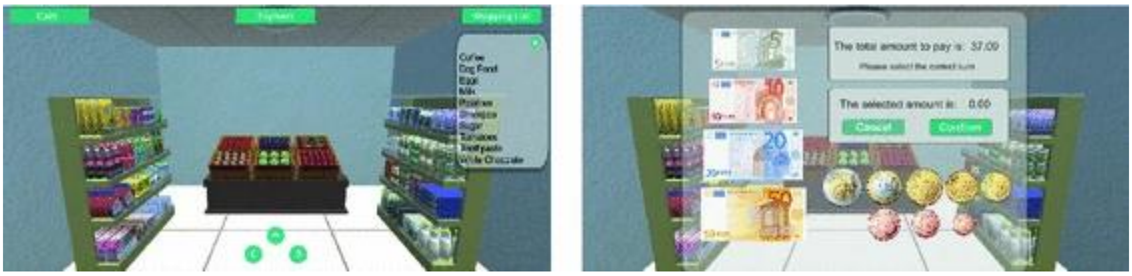


Fig. 15 Snapshots of the Virtual Supermarket serious game (non-immersive visualization).

In [7], we have proposed using the Virtual Supermarket as a cognitive assessment tool, implemented through a serious game, that can be performed remotely on the web using commonly available devices. Our tool provided easy access to an application that can be used by elderly people without specific devices and with minimum support from the doctor. Moreover, such an application could provide a continuous assessment of elderly individuals instead of the sporadic assessment of traditional tests by producing more information for medical services. It is worth noting that such an approach can be without stress for elderly people since they play a game at their own home or in a familiar context (without the presence of a doctor or in a clinic). Figure 16 shows an overview of the system used for the assessment of Mild Cognitive Impairment.

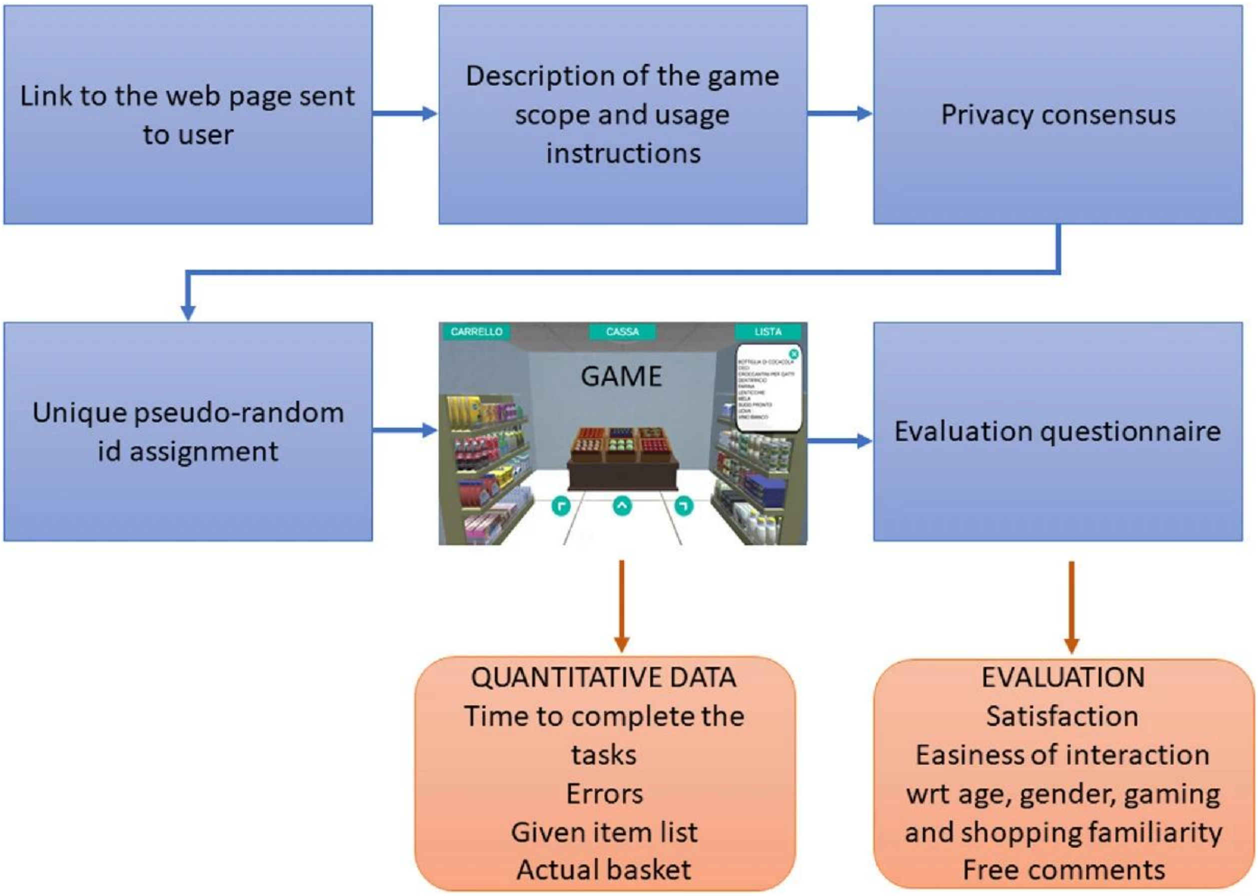


Fig. 16 Overview of the VirtualSupermarket used as an assessment tool for Mild Cognitive Impairment.

In Fit4MedRob, starting from the VirtualSupermarket, we are developing an immersive VR system with the following features:

1. The patient is immersed in a Virtual Supermarket that can be navigated (visual search training).
2. The patient has a list of items to buy, with complexity depending on the gamification aspects (attention and memory domain stimulation).
3. The patient grabs the items from the shelves, with the controller or the hand (visual-motor coordination).
4. The patient goes to the cash desk and pays the due amount (calculation and executive functions stimulation).

The gamification of the environment will take into account the following aspects:

1. Different numbers of items in the list.
2. List always visible, or to be remembered, score computed as a function of the visualizations.
3. Score computed as a function of the correct/incorrect number of items in the basket.
4. Score computed as a function of the time to complete the task.
5. Possibility of having items on the shelves similar but with different visual appearance (distractors).

We refer to [7] and [17] for the evaluation of the currently available VirtualSupermarket and to the future Deliverables for the description of the system being developed within Fit4MedRob.

List of Abbreviations and Definitions

A complete description of the main differences in available technologies has already been provided in D7.1 and D7.4. To facilitate the reading of this deliverable, in the following we provide a short description of the main definitions and abbreviations used in the text.

Gamification: the use of game design elements and principles, in non-gaming contexts to engage and motivate people to achieve specific goals, solve problems, or participate in activities.

EG (Exergame): the term refers to gamified video-based exercises. These games incorporate elements of physical activity and gameplay to promote exercise and improve health outcomes.

SG (Serious Game): they encompass a broader range of applications. They involve incorporating game elements into non-game processes to enhance learning, promote behavior change, and improve outcomes. In Fit4MedRob, they are used to promote cognitive activities.

3D (Three-dimension): it refers to X, Y, Z position of an object in Euclidean space.

VR (Virtual Reality): a computer-generated 3D environment, where people are immersed without external sensorial inputs.

AR (Augmented Reality): an environment that fuses together real-world elements with computer-generated 3D objects, text, and other stimuli.

MR (Mixed Reality): similarly to AR, an environment that fuses together real-world elements with computer-generated 3D objects, text, and other stimuli. When referring to MR, usually the spatial alignment between real and virtual objects, and the visual and perceptual coherency among the different reference frames is addressed.

XR (eXtented Reality): an environment that puts together virtual contents of different kinds, different interaction techniques, and various sensorial stimulations to enhance the "traditional" reality, allowing actions not even possible in the real world. The various modalities of the combination of real and virtual are described in the Milgram Continuum and its extensions [1].

HMD (Head-Mounted Display): a helmet, with 2 displays (one for each eye) and a tracking system that detects the 3DOF or 6DOF position of the head, to correctly update the visualized content (in a way similar to what happens with our vestibular-ocular reflex).

3DOF (Three degrees of freedom): the angles around the three main rotation axes.

6DOF (Six degrees of freedom): the angles around the three main rotation axes and the 3D absolute position.

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