Towards Personalized Mobility Assessment and Rehabilitation: A User Centered Designed VR/XR-Based Solution for Older Adults

Yann Morère
University of Lorraine
LCOMS, EA 7306
Metz, France
email: yann.morere@univ-lorraine.fr

Jérôme Dinet
University of Lorraine
2LPN, UR 7489
Nancy, France
email:jerome.dinet@univ-lorraine.fr

Fabien Clanché
University of Lorraine
UFR STAPS
Nancy, France
email: fabien.clanche@univ-lorraine.fr

Thierry Bastogne
University of Lorraine
CRAN, UMR 7039
Nancy, France
email: thierry.bastogne@univ-lorraine.fr

Matthieu Casteran
University of Lorraine
2LPN, UR 7489 - DEVAH, UR 3450
Nancy, France
email: matthieu.casteran@univ-lorraine.fr

Lucas Detto
University of Lorraine
LCOMS, EA 7306
Metz, France
email: lucas.detto@univ-lorraine.fr

Matthieu Burtin
Mist Studio
Nancy, France
email: matthieu.burtin@miststudio.fr

Frédéric Bousefsaf
University of Lorraine
LCOMS, EA 7306
Metz, France
email: frederic.bousefsaf@univ-lorraine.fr

Kaoutar El Ghabi
University of Lorraine
LCOMS, EA 7306
Metz, France
email: kaoutar.elghabi@univ-lorraine.fr

***Abstract*—This paper presents our project addressing mobility loss in older individuals, funded by the MAIF Foundation for research. *Background:* During the aging process, the prevalence of falls can be mitigated by maintaining mobility as much as possible. Mobility, regardless of age, is a key factor in leading an active and independent life. Aging, by limiting certain abilities, gradually leads to a reduction in mobility. *Method:* In this societal context of generalized population aging, our consortium of researchers and companies aims to develop three interconnected actions to: Accurately evaluate the cognitive-motor performance of older individuals; Stimulate the development of physical and mental skills through motivational exercises; Monitor older individuals in their homes to intervene as early as possible in their care pathways. Our methodology leverages the expertise of the consortium to develop innovative methods serving patients, caregivers, and health professionals to preserve motor, cognitive, and attentional skills, contributing to slowing down senescence. Our working hypothesis is to act early by evaluating and attempting to slow mobility loss. *Results:* User-centered design is at the core of our project. In this paper, we focus on a design phase of a serious game aimed at determining the most relevant avatars and virtual environments (game atmosphere) for our older patient audience. A total of 35 participants were recruited and divided into 7 focus groups of 5 people. To best determine the type of avatar and environment that would suit our target population, we define two independent variables: the avatar and the theme of the environment. They are represented by visual examples, which in our case are presented in five different modalities. At the end of the interviews and after processing the collected data, the analysis of the dependant variables is made showing a categorization according to the participants' preferences.**

Keywords-Virtual and augmented reality; mobility of the older; evaluation; remobilisation; movement activity assesment; focus group.

I. Introduction

Today, individuals over 60 years old represent a quarter of the population and could account for one-third by 2050. Although life expectancy after age 50 in France is the highest in the EU, the number of healthy years lived remains lower than in several other countries [1]. This suggests a projected increase in the number of dependent older individuals, rising from 1.2 million in 2012 to 2.3 million by 2060 [2]. Preventing falls and the loss of autonomy is, therefore, a critical challenge for the coming decade.

Indeed, falls are the leading cause of accidents among individuals over 65 years old. In France, approximately one-quarter of people aged 65 to 85 report experiencing a fall each year, and the frequency of such incidents increases with age [3]. Falls result from a multifactorial interplay of risk factors, including mobility, age, comorbidities, gender, and educational level [4][5]. Their consequences can be severe for affected older individuals, leading to fractures, hospitalizations, loss of autonomy, and even institutionalization. To mitigate this risk, nearly one-fifth of individuals aged 55 to 85 report limiting their movements due to a fear of falling [6].

To address this significant public health issue, various therapeutic approaches have been developed. Multifactorial interventions can reduce the risk of falls by approximately 30% [7].

During the aging process, the prevalence of falls can be mitigated by encouraging mobility in older adults as much as possible. Mobility, regardless of age, is a critical factor for maintaining an active and autonomous life. However, aging, through the gradual limitation of certain capabilities, tends to lead to a progressive decline in mobility.

In regard to the definition of mobility, as formulated by the World Health Organization (WHO) in 2001, the International Classification of Functioning and Disability (ICF) is conceptualized as a universal framework focused on the description of how people live with a health condition [8][9][10]. Three levels of human functioning are classified: 1) body functions and structures as physiological and psychological functions, as well as body impairments, and anatomical deficiencies; 2) limitations in performing tasks or actions; and 3) participation restrictions in daily-life. In [9], functional mobility is defined as the manner in which people are able to move around in the environment in order to participate in the activities of daily living and, move from place to place. Movements include standing, bending, walking and climbing. Functional mobility provides opportunities for a person to engage in physical activities at home, school and in the community thereby contributing to health related quality of life. In our research context, an activity can be defined as the execution of a task or action by an individual, such as walking and the stability required for functional mobility. This phenomenon, influenced by both individual and social factors, results in significant variability among individuals. Consequently, it is not feasible to define a standard level of mobility based solely on a specific age.

Recent studies have highlighted a significant reduction of over 50% in the "life radius" for individuals over 75 years of age. According to these studies, difficulties with walking account for only 2% of mobility challenges, despite walking constituting 40% of the primary mode of movement within this age group [11].

Given the variability in individual situations and the inevitable trend of reduced mobility capacities with aging, it appears crucial to propose a coordinated and personalized approach. Such an approach would involve evaluating mobility, engaging individuals in playful re-mobilization activities, and validating the outcomes through longitudinal monitoring.

In section II, we will describe the final goal of our project, the section III will present the scientific context and the tools used to implement our solutions. The section IV presents a preliminary study concerning the design phase of a serious game aimed at determining the most relevant avatars and virtual environments (game atmosphere) for our older patient audience through focus groups. Finally the section V concludes the communication.

II. Assessment of Mobility

In this broader societal context of an aging population, extended life expectancy, and the aim of maintaining health, mobility in older adults has emerged as a significant concern. According to [12], outdoor mobility is a prerequisite for "aging well," impacting both physical and mental well-being by fostering social exchanges, activities, interactions, and social cohesion [13].

Currently, assessment tools are often limited to evaluation scales like AGGIR, ADL, IADL, WHOQOL-BREF, and EuroQol-5-Dimension. From a technical perspective, the literature features numerous studies on gait analysis in older adults using sensors [14], biomechanical studies employing multi-sensor data fusion [15], and the use of IMU sensors for gait analysis [16]. For instance, Anikwe et al. [17] demonstrates the critical role of mobile health monitoring systems in human health, while Torku et al. [18] present a user-centered approach employing wearable sensors to collect physiological signals and location data. Virtual Reality (VR) and Augmented Reality (AR) have also been explored in studies on older adults' quality of life, though their applications in healthcare contexts remain limited [19]. This study [20] focuses on the effect of immersion in a virtual scenario on mobility during the aging process. Older people exhibited a more reduced locomotor performance in a virtual environment than young adults, thereby their functional mobility score decreased more to complete the task, reflecting the adoption of a more secure locomotion strategy often related to the fear of falling, with an increase in time and number of steps to support balance.

VR and AR have also been explored in studies on older adults' quality of life, though their applications in healthcare contexts remain limited.

In [21], the authors explored the impact of the XR application focusing on exergames for rehabilitation. The paper presented the design rationale and development of an XR application. The evaluation of the system by ten senior users offered encouraging results. These highlighted that the combinatory approach of physical and virtual activities within an immersive and photorealistic VR environment offers an enticing and motivating approach to elder users to improve their physical well-being.

Despite these advances, few studies adopt a comprehensive approach to evaluating the mobility of aging individuals by considering their care journey, healthcare practitioners, and caregivers. Even rarer are those that integrate re-mobilization solutions, minimally invasive monitoring, and an assessment of the impact on quality of life.

Our working hypothesis is to take early action to assess and attempt to slow the decline in mobility. This concept is illustrated in Figure 1.

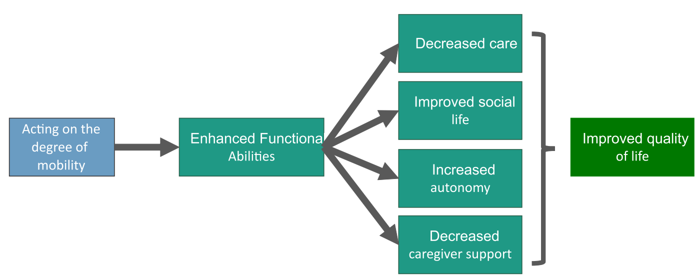

Figure 1. Expected societal impact.

Preserving motor, cognitive, and attentional abilities helps slow the aging process (senescence) [3]. To better evaluate mobility and offer tools for re-mobilization, our project proposes a technological solution for practitioners based on virtual and augmented reality. This solution is designed to collect and identify various mobility indicators, automate experimental protocols and data collection, ensure reproducibility of experimental conditions, and immerse patients in realistic environments and everyday life scenarios [22].

III. Materials and Methods

The following section presents the project's objectives as well as its innovative aspects. The tools and methods used are also introduced.

A. Project Objectives

The development of a stimulating digital tool, based on a gamified approach to physical exercise, aims to enable patients with limited mobility to maintain an appropriate level of physical activity for their upper and lower limbs. It is important to emphasize that rehabilitation in a healthcare center is not accessible to everyone; therefore, the tool should complement and/or extend current care programs.

However, motivational exercises performed independently by patients or older individuals require supervision and a method to assess their impact on the intensity of daily physical activities over a longer period to detect mobility changes. For example, Inertial Measurement Unit (IMU) sensors are increasingly being used to characterize human postures and movements [23][24].

By gathering this information, the identification of new mobility biomarkers should enable automated analysis of individual behavioral strategy evolution. This high-level information, shared among healthcare professionals, patients, and their companions, will enable the implementation of efficient actions throughout the care journey. The proposed solution should facilitate the implementation of coordinated actions. Figure 2 outlines the key objectives of our project.

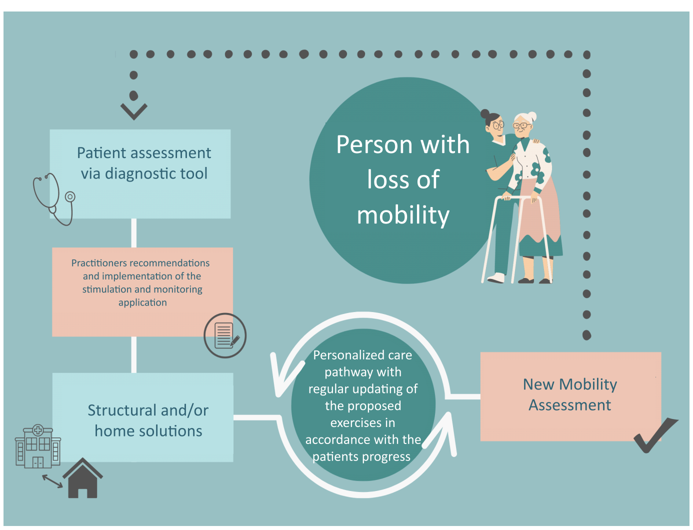

Figure 2. Objectives of the project.

Our technological contribution involves integrating virtual reality immersion technologies with eye-tracking, physiological signal, and movement measurement technologies. This enables us to quantify the cognitive-motor performance of older individuals during health examinations.

By identifying the underlying factors of mobility loss early on and offering a tailored remobilization path, we aim to improve the patient's mobility and reduce the risk of falls.

B. Innovative Aspects

Current tools for detecting fall risk often lack precision in prevention efforts. For instance, in [25] the authors reviewed 25 studies involving 2,314 subjects and found that a Timed Up and Go (TUG) test with a threshold of 13.5 seconds identified only 32% of individuals at risk of falling and yielded a negative result in 73% of subjects with no fall risk. Fall risk arises from numerous factors linked to the interaction between the patient and their environment. Attention, cognitive, or motor deficits, combined with environmental disturbances or distractions, can disrupt the motor control of a patient, potentially creating risky situations, as illustrated in Figure 3 [22].

To better address the multifactorial nature of fall risk, some test protocols assess motor abilities in scenarios that also involve manual or cognitive tasks [26]. It has been observed that incorporating a manual or cognitive task enhances the discriminative power of the TUG test.

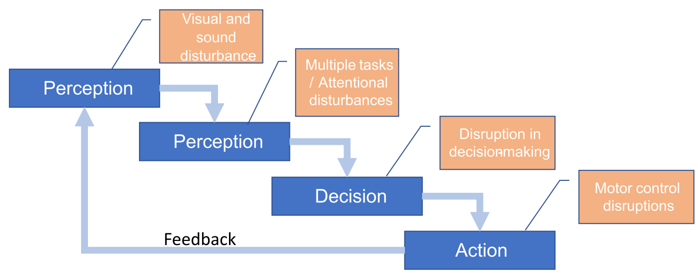

Figure 3. Motor control loop and its disturbances.

Environmental challenges faced by patients must be considered in fall risk assessments. For instance, tripping over obstacles is a major cause of falls [27]. Navigation around and over obstacles varies between younger and older individuals [28]. The height of the foot during obstacle crossing has been shown to predict fall risk [29]. Unlike the TUG test, these tests are challenging to implement in clinical settings as they often require specialized measurement equipment and post-processing of kinematic data.

To enhance diagnostic accuracy, we propose an experimental protocol informed by clinical practices and existing research protocols. This solution leverages VR and AR technologies combined with motion tracking sensors, eye-tracking devices, and physiological signal monitors to provide a comprehensive evaluation of a patient's condition during testing.

The experimental data acquired in a realistic environment will allow the assessment of motor, cognitive, and attentional capacities, as well as the emotional state of the patient. An integrated analysis of these data will define mobility indicators aimed at enhancing diagnostic accuracy. Participants will be immersed in a VR scenario, creating standardized audiovisual stimuli to measure motor responses to various perturbations. Motor responses will be captured using VR/AR system sensors, quantifying reaction times and adaptation strategies.

Unlike traditional methods, which rely on basic decision rules, our evaluation will initially use scientifically validated statistical techniques. Once a substantial dataset is collected, we will employ artificial intelligence (AI) techniques to construct predictive models of fall risk. This approach will enable healthcare personnel, even non-specialists, to perform fall risk diagnostics.

Our project aims to replace simplistic decision-making methods with advanced algorithms, providing a detailed and nuanced diagnostic prediction. This enhancement will help identify the optimal care pathways for patients. A critical step in this process involves defining interpretable biomarkers of fall risk that are easily understood by medical professionals. These biomarkers will serve as the foundation for creating precise and actionable prognostic tools.

C. Tools

To address these challenges, numerous clinical tests have been developed to assess patients' motor skills. We propose a tool leveraging virtual and augmented reality that implements tests inspired by existing literature, allowing for the evaluation of patients' motor, cognitive, and attentional capacities in an immersive, realistic environment.

For this project, we aim to develop three interconnected actions (see Figure 4):

- Precisely assess the cognitive-motor performance of older individuals;
- Stimulate the development of physical and mental skills through motivational exercises;
- Monitor older individuals at home to intervene as early as possible in their care pathway.

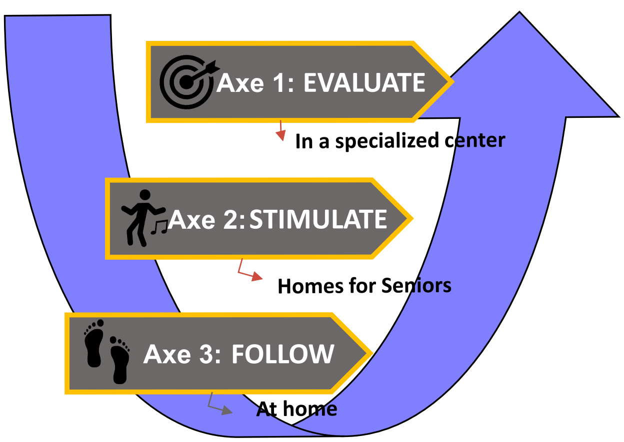

Figure 4. Methodology to slow down mobility loss.

Our methodology relies on the combined expertise of the project consortium to develop innovative methods that benefit patients, caregivers, and healthcare professionals.

User-centered design is at the core of our project. All methods and tools are selected in collaboration with the final users of our applications. To this end, we have involved two specialized partners in the project: OHS Lorraine (Office d'Hygiène Sociale de Lorraine http://ohs-solutions.fr/), and ONPA (Office Nancéien des Personnes Âgées https://onpa.net/). Both of which focus on enhancing the autonomy of individuals affected by aging.

A preliminary study [30] allowed us to identify acceptable and practical equipment for the target population based on the project's objectives. This study resulted in the design of a solution consisting of three specific development axes:

- Axis 1: Detailed Patient Assessment in VR/AR . This application focuses on conducting detailed mobility assessments using VR/AR. It incorporates various mobility tests, notably the Timed Up and Go (TUG) test, performed in an immersive virtual environment to simulate conditions closely resembling the patient's daily reality (see Figure 5). In addition to motion tracking for mobility characterization and gaze monitoring, specific physiological signals of the patient (e.g., AED, ECG) will be acquired through a non-invasive wireless system to enrich the evaluation. For instance, the detection of stress caused by fear of falling will be included. This test can be repeated as often as necessary, such as after a physiotherapy regimen or when home monitoring signals a significant decline in mobility.

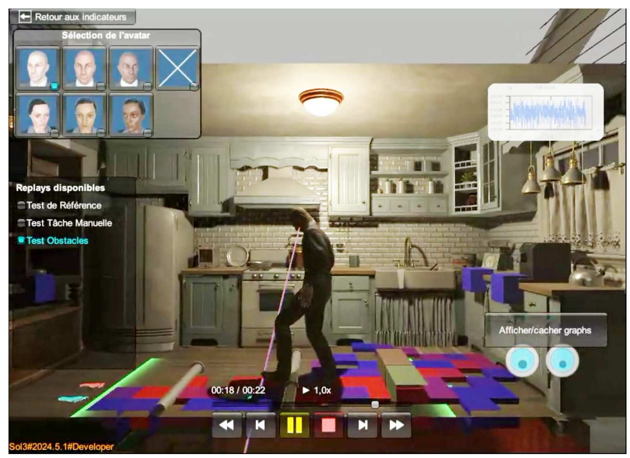

Figure 5. Mobility assessment in Virtual environment (Axis 1)

- Axis 2: Patient Remobilization through VR and AR Exergames. This immersive re-training application in VR/AR enables healthcare practitioners to design a personalized "virtual prescription" comprising a list of exercises tailored for the patient to perform using the application (see Figure 6). At the end of each session, the practitioner will receive a detailed summary of the patient's activities, allowing comparison with previous sessions. This feedback loop ensures continuous monitoring and adaptation of the rehabilitation plan based on the patient's progress.
- Axis 3: Patient Mobility Monitoring in Autonomy. This application interfaces with an inertial measurement unit (IMU) carried by the patient during their daily activities at home (see Figure 7). The system continuously tracks the patient's mobility, capturing detailed data on their movement patterns and behavioral strategies within their living environment. By analyzing these patterns, healthcare providers can monitor changes in mobility, identify early

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Figure 6. Graphic Universe of VR/AR Remobilization Exercises (Axis 2).

signs of functional decline, and intervene promptly with appropriate therapeutic strategies. The goal of this axis is to complement clinical assessments with real-world, day-to-day mobility data, offering a comprehensive understanding of the patient's condition and enabling personalized care plans.

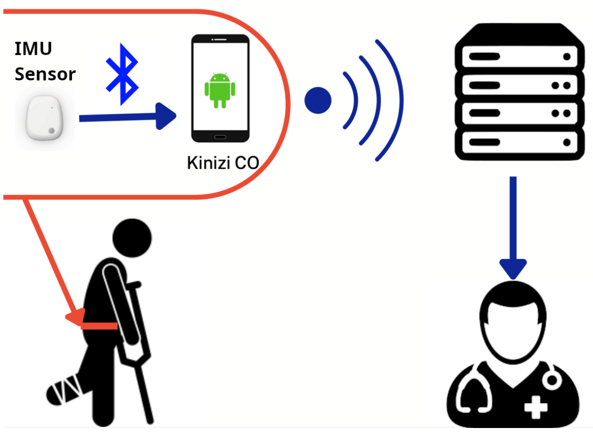

Figure 7. Home mobility monitoring (Axis 3).

D. Materials and Software

Depending on the different axes of the project, various materials will be used, ranging from the most complex acquisition systems (Axis 1) to the simplest and lightest ones for monitoring (Axis 3), and a gamified virtual/augmented reality remobilization system for Axis 2.

For Axis 1, the following materials have been selected (cf. Figure 8):

- HTC XR Elite headset, as it features a passthrough system allowing it to be used in both VR and AR. It also includes eye-tracking through an optional module. Its API enables natural hand interaction without the need for joysticks.
- In addition, HTC Ultimate trackers and Wrist trackers will be used due to their high accuracy [31][32] for tracking the trunk and limb positions during user activities.
- Physiological signals from the person will be recorded using a TEA Captiv [33] system with wireless, minimally invasive sensors.
- The entire evaluation application is developed using Unity for the real-time serious gaming part and Blender for modeling. The various HTC and TEA APIs are interfaced in C# with Unity.

Figure 8. Axe 1 devices: HTC XR Elite and TEA wireless sensors.

For Axis 2, our partner Mist Studio [34] has selected the Meta Quest 3 VR/AR headset (cf. Figure 9). This state-of-the-art headset offers excellent technical specifications and is easy to use. A first gamified exercise is currently under development, and the results section will address the choice of avatars and the theme of the serious game environments by analyzing the opinions and attitudes of older people *a priori* through a study conducted using focus groups.

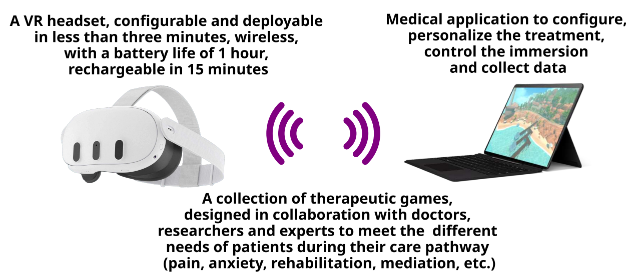

Figure 9. Axe 2 devices : Meta QUest 3 and dedicated applications.

Axis 3 focuses on the longitudinal monitoring of users' mobility. To achieve this, our partner Cybernano [35] conducted a study to select an Inertial Measurement Unit (IMU) sensor that meets user requirements identified in the study [30], as well as technical requirements such as weight, sensor storage capacity, battery life, and Bluetooth data download speed to the smartphone. After conducting an experimental study to compare several products on the market, the MetaMorionR sensor from MBIENTLAB was chosen. At 11 grams, it satisfies all the required criteria.

This sensor is integrated into a complete information transfer ecosystem. A Proof of Concept (POC) has been developed using the architecture shown in Figure 10. To implement this part of the project, a mobile application (named KINIZI), a web application (also named KINIZI), and a library (named libkinizi-playground), which serves as the foundation for applications using sensors to collect data, have been developed. The next step is to conduct real-world testing.

Security requirements related to data storage were considered during the architecture design. However, the device will be classified as "Wellness" rather than "Medical Device" to avoid costly certifications for the startup Cybernano.

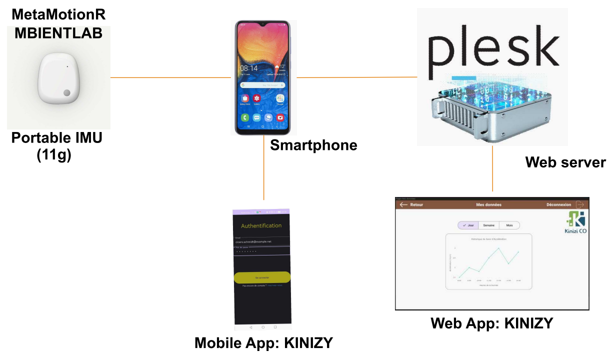

Figure 10. Axe 3 devices : MetaMotionR IMU and data acquisition architecture.

The final part of this communication focuses on the user-centered study that helps determine the most relevant avatars and environments for our older patient audience in the context of Axis 2: exergames for remobilization.

In this phase of the project, we aim to gather insights from older adults to identify avatars and virtual environments that resonate with them. This will ensure that the exergame is not only motivating but also relatable and enjoyable. To achieve this, a study using focus groups was conducted to better understand the preferences, opinions, and attitudes of older adults regarding the design of avatars and environments in exergames. This feedback will be essential to create a more engaging and personalized experience for users, which is crucial for ensuring long-term participation and effectiveness in physical rehabilitation.

This approach is rooted in the broader trend of "user-centered design," which prioritizes the needs, abilities, and preferences of the end-user—in this case, older adults—in order to create a more effective and user-friendly tool. The goal is to make the exercise more accessible and motivating for users, helping them stay engaged with their rehabilitation while providing measurable benefits for their mobility and overall health.

IV. User oriented avatars and environments design

This preliminary study focuses on the application of virtual/augmented reality remobilization in Axis 2. It consists in the design phase of a serious game aimed at determining the most relevant avatars and virtual environments (game atmosphere) for our older patient audience.

The representation of humans in virtual reality as avatars is a complex task because it is influenced by several factors such as the "Proteus effect" [36][37][38][39] and the Uncanny Valley [40].

The "Proteus effect" means that the avatar is not just a simple costume but a "full and complete self-representation" that enables two processes [41]: *deindividuation*, which is the alteration of self-awareness and the ability to critically assess one's actions, and *rationalization*, which means that individuals influence their own attitudes and behaviors in the virtual environment in line with the identity cues conveyed by the avatar. The Uncanny Valley, on the other hand, is the discomfort felt when avatars or robots appear "too close" to human but not quite human-like enough [42]. However, according to a more recent study [43], this phenomenon seems to be less pronounced among older people.

To define the avatars and environments for the exergame, a study was conducted through interviews with the target population using focus groups.

A. Participants

A total of 35 participants were recruited and divided into 7 focus groups of 5 people. The average age was 73.2 years with a standard deviation of 5.7 years. The youngest participant was 68.3 years old, and the oldest was 82.1 years old. The study included a majority of women (29 out of 35 participants, or 82.8%). The educational levels were distributed as follows: pre-Baccalaureate (82.8%), Baccalaureate (8.5%), and post-Baccalaureate (8.7%).

B. Protocol

The protocol for a focus group interview session is described in Figure 11.

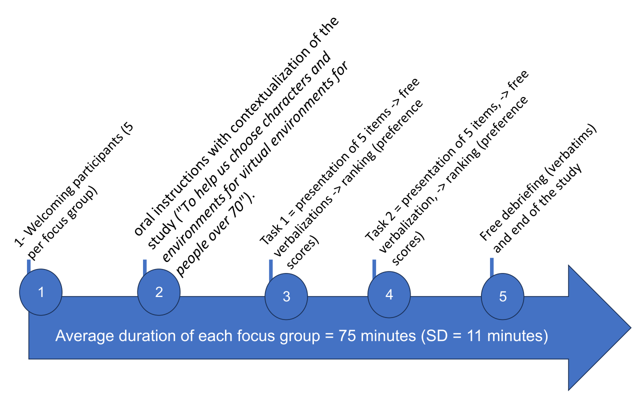

Figure 11. Focus group protocol

C. Method

To best determine the type of avatar and environment that would suit our target population, we define two independent variables (IVs), which are the factors manipulated during the study: the avatar (IV1) and the theme of the environment (IV2).

These independent variables are represented by visual examples, which in our case are presented in five different modalities (cf. Figure 12).

We then define the dependent variables (DVs) that will serve as our measures: a preference score from 0 to 10 (DV1), and the frequencies and occurrences of the adjectives and nouns produced during the interview (DV2).

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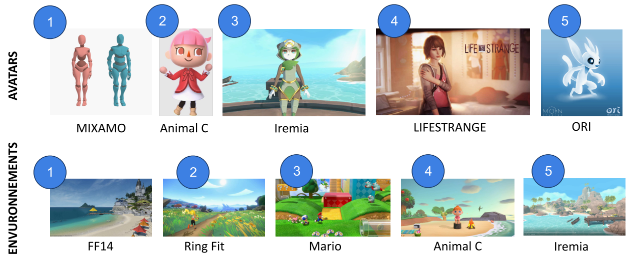

Figure 12. Independent variables : Avatars and environment

The overall analysis plan (AP) is given by the following relationship.:

$$AP = S_{35} \times IV1_5 \times IV2_5$$

We also formulate several control variables to avoid biasing the experience:

1) Counterbalancing of items for each task (to avoid an order effect);
2) Counterbalancing of the two tasks (to avoid an order effect);
3) The same avatars and environments are presented;
4) "Limited" experience with digital environments (online games, smartphone games);
5) No severe cognitive impairments;
6) The same facilitator for all focus groups;
7) Avatars and environments are presented according to a number (to avoid vocabulary effects);
8) Use of the same video projector (1800 lumens);
9) Same projection size (75-inch screen);
10) Same distance between participants and the screen;
11) No known or proven speech disorders;
12) Correct vision declared (correction for 80% of participants);
13) Data collection during the month of July 2024.

D. Results

At the end of the interviews and after processing the collected data, the analysis of the VD1 variable (preference score, see Figure 13) clearly shows a strong preference for three avatars (3, 2, and 4), with a notable disappointment for avatars 5 and 1. There is also a significant difference between the two categories (4 vs 5, $p < .001$). However, it is worth noting that there are individual differences, likely due to the Proteus effect.

Figure 13. Results : preference score for avatars

Similarly, we analyze the variable IV2 related to environments (see Figure 14). A clear preference is observed for environments 5, 2, and 1 in terms of average scores. Opinions are more reserved for the last two environments, 4 and 3. As with variable IV1, a significant difference is observed between the two categories 1 and 4 ($p < .001$). On this variable, fewer inter-individual differences are noted, with many significant positive correlations (see table I).

Some additional remarks can be issued from the Table 1:

- There is a negative and significant correlation between opinions for avatars 1 and 5, the first one being very robot-like while the second being more "fun";
- There are positive and significant correlations between opinions about environments 1, 4 and 5. These three environments represent a beach in a very pleasant way;
- In the same way, there are positive and significant correlations between environments 3 and 4, and between environments 4 and 5 which represent "simple" and funny physical environments extracted from video-games;

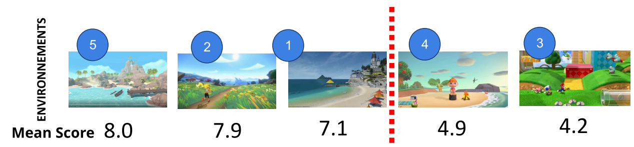

Figure 14. Results : preference score environments

Figures 15 and 16 display the results for the variable DV2: frequencies and occurrences of adjectives and nouns produced during the interviews for the independent variables Avatar and Environment.

These figures offer a detailed breakdown of how participants described the different avatars and environments, providing insight into their preferences and the associations they made with each option. By examining the frequency of terms, we gain a deeper understanding of the emotional and cognitive responses of the older participants toward various virtual representations and settings.

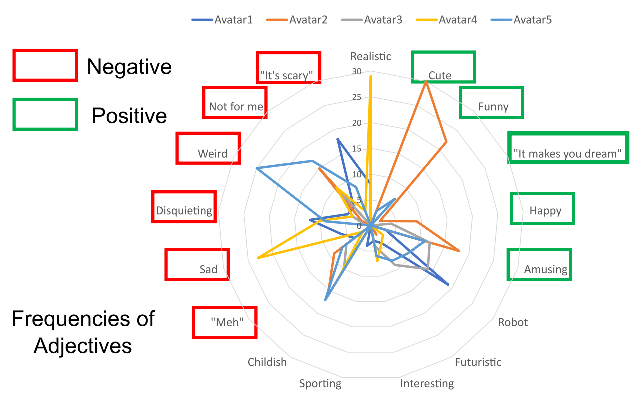

Figure 15. Results : frequencies and occurrences of adjectives and nouns for avatars

Adjectives with positive (green), negative (red) and neutral meanings can be classified.

The adjectives can be categorized as positive (in green), negative (in red), and neutral. This classification helps to further understand the participants' emotional and cognitive responses toward the avatars and environments they encountered during the interviews. Positive adjectives reflect favorable perceptions,

TABLE I. GENERAL CORRELATION MATRIX

		Avat.1	Avat.2	Avat.3	Avat.4	Avat.5	Env.1	Env.2	Env.3	Env.4	Env.5
Avat.1	Pearson's r	–	×	×	×	×	×	×	×	×	×
	p-value	–	×	×	×	×	×	×	×	×	×
Avat.2	Pearson's r	0.203	–	×	×	×	×	×	×	×	×
	p-value	0.243	–	×	×	×	×	×	×	×	×
Avat.3	Pearson's r	0.132	0.260	–	×	×	×	×	×	×	×
	p-value	0.451	0.132	–	×	×	×	×	×	×	×
Avat.4	Pearson's r	0.007	0.408 *	0.105	–	×	×	×	×	×	×
	p-value	0.967	0.015	0.548	–	×	×	×	×	×	×
Avat.5	Pearson's r	-0.526 **	0.194	-0.176	0.209	–	×	×	×	×	×
	p-value	0.001	0.263	0.312	0.229	–	×	×	×	×	×
Env.1	Pearson's r	0.002	-0.309	0.011	-0.283	-0.064	–	×	×	×	×
	p-value	0.992	0.070	0.950	0.099	0.715	–	×	×	×	×
Env.2	Pearson's r	-0.004	-0.211	-0.105	-0.105	-0.033	0.925***	–	×	×	×
	p-value	0.983	0.224	0.547	0.550	0.846	<0.001	–	×	×	×
Env.3	Pearson's r	-0.082	0.140	-0.039	0.031	0.025	0.040	-0.029	–	×	×
	p-value	0.642	0.423	0.822	0.860	0.888	0.818	0.867	–	×	×
Env.4	Pearson's r	-0.070	-0.153	0.133	-0.339*	-0.051	0.577***	0.334*	0.694***	–	×
	p-value	0.691	0.380	0.447	0.047	0.773	<0.001	0.05	<0.001	–	×
Env.5	Pearson's r	-0.52	-0.241	-0.035	-0.213	-0.038	0.945***	0***.936	0.103	0.539***	–
	p-value	0.768	0.164	0.840	0.220	0.828	<0.001	<0.001	0.555	<0.001	–

Note : $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

such as describing avatars as "friendly" or environments as "relaxing." Negative adjectives, on the other hand, indicate discomfort or dissatisfaction, like "unclear" or "strange." Neutral adjectives might indicate ambivalence or a lack of strong opinion, such as "ordinary" or "simple."

This categorization provides valuable insight into the participants' preferences and the overall emotional impact of the virtual elements used in the study. By analyzing these frequencies and occurrences, researchers can refine the avatars and environments to better suit the needs and expectations of older users.

As Figure 15 shows, participants produced more positive adjectives for two avatars (avatars 3 and 4, perceived as "cute", "funny", "happy", "amusing"). In the same way, as Figure 16 shows, participants produced more positive words for three environments (environments 1, 2 and 5, perceived as "calm", "funny", colorful", "paradisaical", "exotic").

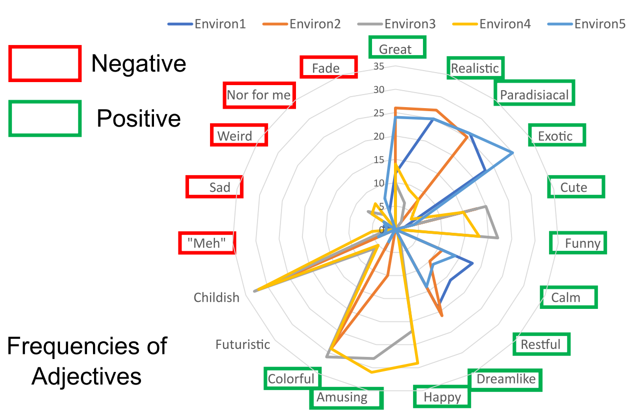

Figure 16. Results : frequencies and occurrences of adjectives and nouns for environments

These opinions and attitudes *a priori* allowed to highlight clear preferences for certain avatars and for certain environments (see Figure 13). Thanks to this study, we can conclude about the possible choices in terms of avatars and environments in line with our target population. The preferred combinations, i.e., the best combination according to the participants, are summarized in Figure 17.

Figure 17. Possible choices for avatars and environments

E. Discussion

Although the results were significant, a number of limitations emerged. The first concerns the static nature of the avatars and environments proposed. Participants would have liked to see avatars in action and made comments such as: "It doesn't move", "What can it do?", "It's weird, everything is frozen...".

As the precise context of use was not presented, the participants also asked the following questions : "But what is it for?", "Is it for playing games?

As in our previous study [30] the impact of personal experience is very important and can modify the study : "With my grandson, I sometimes play this thing", "I've already seen it on TV", "It looks like my granddaughter".

There was no objective assessment of our participants' sensitivity to colour and contrast, which led to comments such as: "I can't see anything at all", "What's that in the background, water or mountains?

We did not escape the uncontrolled group effects (majority influence, minority influence, leadership, etc.) which interfered with our study. This is reflected in phrases such as : "Well, if others think that, then...", "Would you use that later? Well, I'll be damned".

V. Conclusion

This paper gives an overview of our project to address the loss of mobility in the older. Using 3 axes of action: assessment, remobilization and follow-up, we aim to slow down the loss of mobility and thus ultimately increase quality of life. To achieve this, we will be developing technological tools based on virtual and augmented reality, as well as longitudinal mobility monitoring using sensors worn by the patient. The general principles of these 3 development axes were described. The second part of the presentation focused on the development method used, which constantly puts the end-user at the heart of the development process, making him or her an active participant in the choices made. Thanks to a focus group method, we were able to determine the most relevant avatars and virtual environments (game atmosphere) for our older patient audience. These highlights will be incorporated into new virtual and augmented reality scenarios to assess and improve the mobility of the older. Ultimately, this solution could help in the care of the older by providing healthcare professionals with a precise and effective tool for assessing and monitoring changes in mobility. The next stages of the research involve extending the tests to a larger sample and developing more advanced rehabilitation functions, in order to confirm the results obtained and assess the long-term impact of this approach on the quality of life of the older.

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