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Design and Evaluation of a Memory-Recalling Virtual Reality Application for Elderly Users

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Abstract: Virtual reality (VR) can be useful in efforts that aim to improve the well-being of older members of society. Within this context, the work presented in this paper aims to provide the elderly with a user-friendly and enjoyable virtual reality application incorporating memory recall and storytelling activities that could promote mental awareness. An important aspect of the proposed VR application is the presence of a virtual audience that listens to the stories presented by elderly users and interacts with them. In an effort to maximize the impact of the VR application, research was conducted to study whether the elderly are willing to use the VR application and whether they believe it can help to improve well-being and reduce the effects of loneliness and social isolation. Self-reported results related to the experience of the users show that elderly users are positive towards the use of such an application in everyday life as a means of improving their overall well-being.

Keywords: virtual reality; elderly users; application design

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1. Introduction

In recent years, the use of virtual reality applications by the elderly has increased rapidly [1,2]. A number of research studies concluded that virtual reality (VR) applications have the potential to positively influence elderly users to entertain themselves through virtual games [3], to provide a means for exercising in virtual spaces [4,5], or to support them in dealing with fears [6]. Along these lines, the aim of our work is to design and evaluate a user-friendly and enjoyable virtual reality application that can support elderly users in dealing with the effects of loneliness and social isolation [7] that are common among their population. The proposed application presents familiar photographs of elderly users in a VR environment, populated with a virtual audience that acts as a virtual companion to the user. The familiar photographs presented aim to awaken the emotions, either positive or negative, of the users who are asked to narrate memories from their younger years and discuss their memories with the virtual audience through a storytelling experience. Within this context, the photographs displayed in the application aim to activate a memory-recalling experience, and the presence of a virtual audience aims to motivate users to engage in storytelling so that feelings of loneliness and social isolation are alleviated. The ultimate purpose of the research is to study whether the users of the proposed virtual reality application believe that it has the potential to improve their emotional state with regards to feelings of loneliness, joy, and well-being. Experimental results derived through the evaluation of the application by elderly users indicate that the use of the proposed application is well received by the target population since most users were positive about using it to reduce feelings of loneliness and social isolation.

In the remainder of the paper, we present a literature review on the topic of VR applications and the elderly. The multi-phase co-design methodology used for designing and implementing the VR application is presented in Section 3, and in Section 4, the final VR application is described. Section 5 focuses on the experimental evaluation of the VR

application based on interviews and questionnaires. A discussion about the results of the experiment is presented in Section 6, and conclusions and plans for future work are presented in Section 7.

2. Literature Review

Encouraging interaction between older adults and contemporary technology is widely advocated. Beyond connecting with loved ones, technology aids seniors in enhancing social connections, accessing valuable health information, participating in civic decision-making, and maintaining physical well-being through specialized fitness applications [8]. Several applications designed with a human-centered design approach aimed at motivating older people to use applications for the benefit of their health are reported in the literature. Mostajeran et al. [9] describe the design of an augmented reality application where virtual coaches provide a solution to elderly people who face balance problems and are at risk of falling. Rose et al. [10] investigated the challenges during the design and implementation of a VR system for physical training targeting patients with dementia. Lera et al. [11] describe an architecture for human–robot interaction known as MYRA, employed in the development of a system assisting the elderly with medical dose management. This system incorporates augmented reality (AR) to enhance robot interaction. The prototype allows users to easily adhere to medical guidelines for daily pill dosage by presenting the pillbox to the robot or a camera, facilitated by augmented reality. The study concludes that the integration of AR has demonstrated positive effects on the user experience.

VR holds great promise as a tool that could improve the treatment of cognitive and emotional disorders in the elderly. While VR applications have been successfully used in clinical environments with adolescents and children, there has been comparatively less research conducted on VR applications in the geriatric population [12]. Gao et al. [13] assert that virtual reality technology serves as a valuable tool for effectively treating the elderly. This involves utilizing non-immersive VR in corridor settings or immersing patients in realistic environments, such as urban landscapes or parks, through head-mounted displays or within a CAVE system. This approach enhances physical and occupational therapy sessions, thereby elevating the likelihood of successful adaptation to the real world. There are many applications related to user reactions [14] when they interact with virtual audiences in VR applications. Most of these applications target the therapy of users who fear presenting to a real audience.

There is insufficient empirical research on the use of immersion technology and the immersion experiences of elderly users. The results of previous studies show that immersion experiences are related to the physical, mental, and social functions of the elderly, especially video game-based educational games that can be beneficial in improving sensory and motor skills, perception, and knowledge and also assist in forming relationships with grandchildren. Artificial intelligence-based robots used for social care promote social exchange and emotional relaxation, and the use of exciting content can enhance life satisfaction and family ties [15]. Lin [16] describes how virtual reality affects the emotional and social well-being of the elderly through the Rendever VR platform. The study was conducted with sixty-three residents from four assisted communities and lasted two weeks, where residents interacted with one of two intervention conditions—VR (i.e., experimental mode) or television (i.e., control status). The results showed that VR provided more positive results than the control group that used a TV with the same content. The researcher concludes that VR has the potential to improve the well-being of the elderly.

Ma et al. [17] indicate that employing virtual reality for mindfulness training is a successful and inventive approach for enhancing mental health conditions among adults. Along these lines, Matsangidou et al. [18] explored challenges encountered in developing, testing, and implementing a virtual reality system for physical training tailored to individuals with moderate to severe dementia. The system was introduced in a confined mental health unit, leading to the formulation of recommendations for the design of virtual reality systems in healthcare. Employing an iterative participatory design approach, health experts

from various fields and 20 individuals with moderate to severe dementia contributed their insights. The analysis highlights the potential of virtual reality physical training for people with dementia and offers a set of guidelines and recommendations for future healthcare deployment. It is thought that encouraging people with generalized anxiety disorder to perform aerobic exercise as a stress-reduction strategy can be accomplished through virtual exercise therapy [19]. Tammy Lin et al. [20] show that the Proteus effect, which involves adjusting avatar age in virtual reality, works well for older people when they exercise. The findings demonstrated that, for older individuals who did not participate in strenuous exercise, the virtual reality embodiment of younger avatars causes a greater perceived exertion of exercise.

Following an extensive review of the literature, it was determined that our research diverges in specific aspects, prompting a desire for further exploration in those particular areas. Initially, the involvement of the virtual audience in interacting with the user through their physical presence in the virtual space and through audio instructions was not considered in previous approaches. Furthermore, the proposed application focuses on simplicity and execution on low-cost VR devices, allowing elderly users to use the application without requiring extra assistance or dedicated equipment. Finally, it should be noted that the application aims to help users recall memories from the past. As indicated in the relevant literature, activities that involve storytelling [21,22] and memory-recalling exercises [23] support the prevention of mental diseases in the elderly population. Hence, it can be inferred that the use of the proposed application has the potential to prevent mental diseases associated with brain inactivity.

3. VR Application Design Methodology

The development of the proposed VR application followed a multi-phased co-design approach with the active participation of groups of people related to the elderly, such as caregivers, medical personnel, and elderly users. Furthermore, professionals with expertise in the development of virtual reality applications were also involved in the design process. The main phases of the design (see Figure 1) include the literature review in relation to user requirements and previous approaches in designing VR applications for the elderly, the design and evaluation of a pilot test application, the refinement of design elements of the application through a questionnaire-based approach, the development of the final application, and the evaluation of the application with the target population of elderly users. This paper focuses on the last two phases of the design process. However, brief descriptions of the remaining phases are also presented.

Phase 1—Literature Review: The aim of the literature review was to determine the needs of the elderly and study age-related difficulties and weaknesses that should be taken into consideration when designing an elderly-friendly VR application. In addition, previous approaches to developing VR applications for the elderly population were studied.

Phase 2—Pilot Application and Evaluation: A prototype virtual reality tool that allows elderly users to deal with the problems of social isolation while providing an entertaining brain-triggering activity was developed. An initial user evaluation provided information related to the strengths and limitations of the prototype application that guided the process of optimizing the application for elderly users [24].

Phase 3—Refining Design Elements of the Application: Based on the outcome of the evaluation of the pilot application, several design elements were refined through a questionnaire-based data gathering process, where participants rated different design options for the final application. The design elements under evaluation included the choice of subject, number, and chronological period of the photographs portrayed in the application. Furthermore, in an attempt to maximize the impact of the application, the characteristics of the virtual audience that appears in the VR application were optimized [25].

Phase 4—Application Development: Having collected information that identified the target audience's needs, the final application was developed.

Phase 5—Evaluation of the Final Application: A comprehensive evaluation of the final application by members of the target population was carried out, and conclusions related to the effectiveness of the application were derived.

More details of Phases 4 and 5 are presented in subsequent sections.

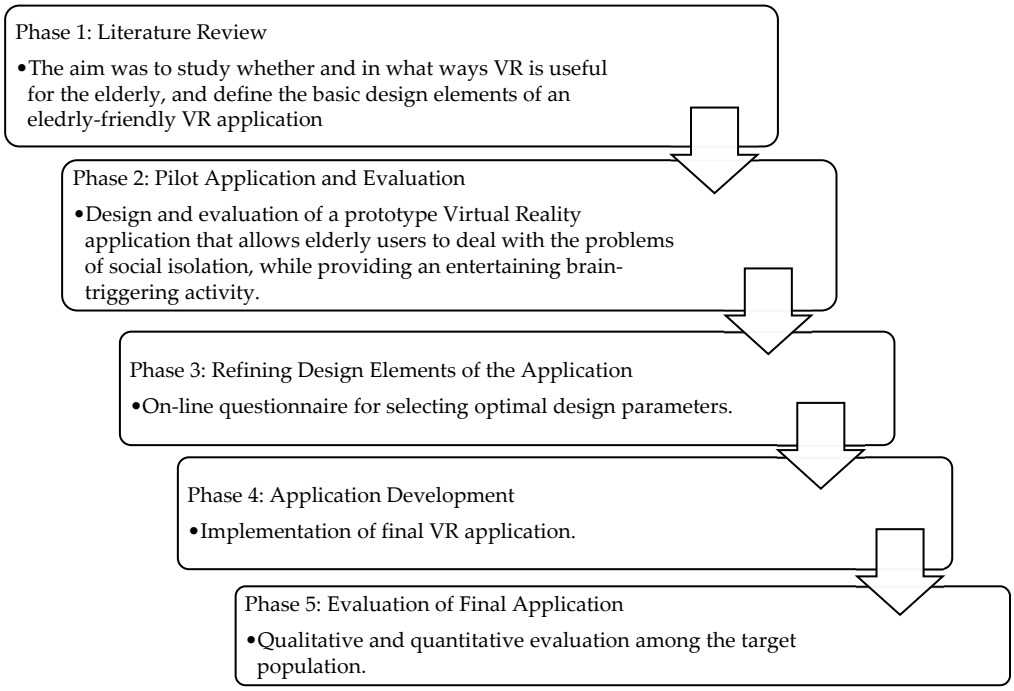

Figure 1. Diagram with the stages followed in the research methodology.

4. VR Application Description

In this section, a description of the operation of the VR application is presented. The VR application runs on VR-compatible smartphones in conjunction with the use of low-cost VR headsets. When the application starts, instructions are provided to the user explaining how to use the application. Then, the user is asked to indicate his/her place of origin so that appropriate photographs are selected (see Figure 2), and then the user is instructed to place his/her smartphone in the VR headset. When the user wears the headset, he/she is immersed in a scene showing a forest, billboards displaying the selected photographs, and a virtual audience. Four billboards with photographs attached are placed in a semi-circle so that the user is able to view all the photographs just by turning his/her head around 180 degrees (see Figure 3).

In line with feedback obtained during the design process [25], the virtual audience consists of seven avatars depicting adults and children (see Figure 4), so that the group resembles a family gathering. Avatars are placed near the user so that continuous optical contact between the user and the audience is ensured. Bearing in mind that elderly users are more prone to nausea effects when immersed in a VR environment [26], both the user and the virtual characters do not move around, so the effects of nausea [27] are minimized. However, the virtual characters perform animations so that the user has the feeling of interacting with real humans [28]. In order to strengthen interactions with the user, audio instructions are heard from the virtual audience to encourage the user to start the narration. At the same time, low-pitched nature sounds are heard in the background to achieve more immersion and relaxation for the user.

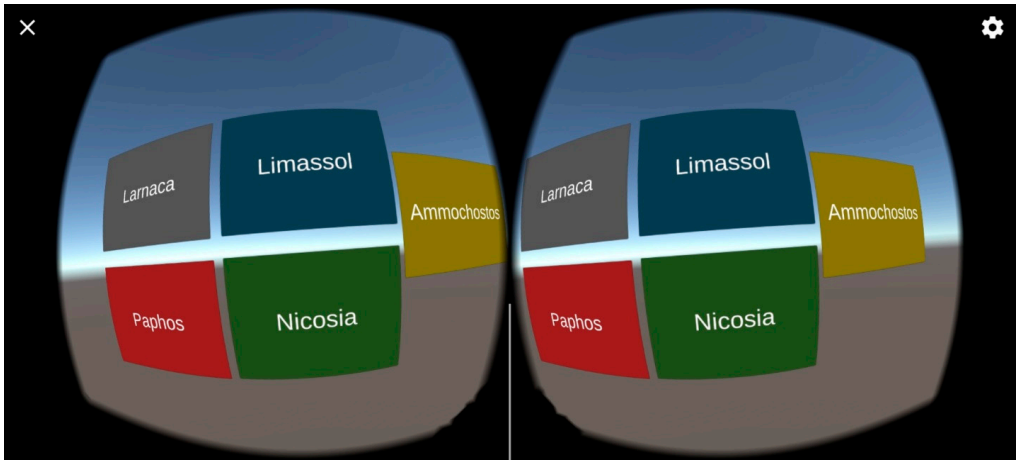

Figure 2. Screenshot of the application showing the main menu that allows the user to select his/her place of origin.

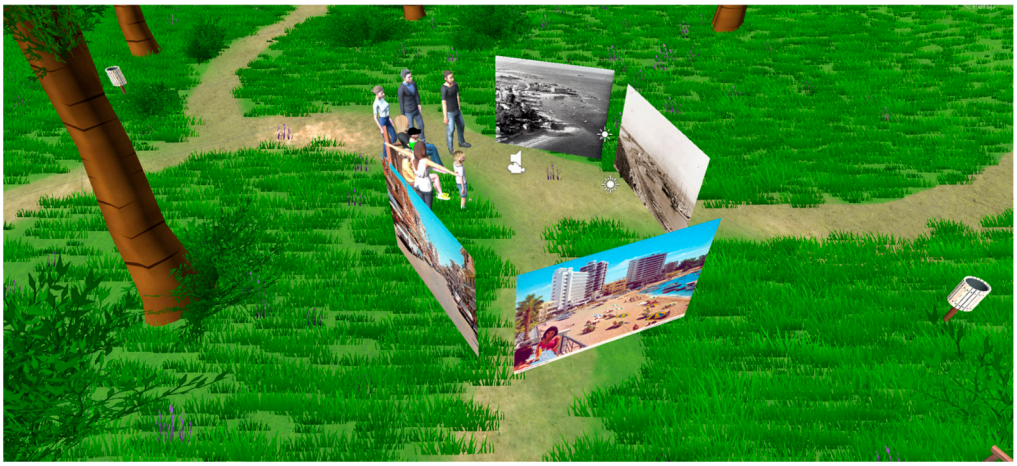

Figure 3. Screenshot of the VR environment showing the photos and avatars.

Figure 4. Screenshot of the virtual audience as seen from the user's point of view.

The application was created using the Unity3D platform and is compatible with smartphones, allowing users to utilize it with affordable portable VR headsets. The only prerequisite is for the smartphone to have a gyroscope for tracking user head movements. The cost of a suitable VR headset typically ranges from 5 to 50 euros, and a compatible

smartphone starts at around 150 euros. Considering that a majority of elderly individuals already possess smartphones, the minimal additional cost of a VR headset is unlikely to deter most users from employing this application in their homes. The primary challenge associated with low-cost VR headsets is an increased risk of cyber-sickness [27]. To mitigate this issue in the proposed application, the speed of movement is restricted to avoid sudden changes in viewpoint, and users are encouraged to use the application while seated.

To use the audio instructions of the virtual audience, the Narakeet tool [29] was used so that the avatar voices sounded realistic. The application environment as well as some elements of the application have been selected from the Unity Asset Store. The avatars were selected from the Unity Asset Store [30], and the animations were selected from Mixamo.com (accessed on 27 January 2024) [31]. The choice of movements selected for this application includes typical body movements adopted during a conversation, increasing the realism of the virtual audience.

5. Experimental Evaluation

The aim of the evaluation is to use self-reported data to assess the impact of the application on elderly users. More specifically, we aim to determine whether elderly users believe that the proposed VR application could help them reduce feelings of social isolation and loneliness, could offer and stimulate their interest in telling stories from their younger years, and finally to study whether the application could improve their overall sense of well-being. Other issues related to the usability and attractiveness of the application were also investigated. The following research questions were posed:

- Research Question (RQ1): Are elderly people willing to use the virtual reality application?
- Research Question (RQ2): Do elderly people believe that the VR application can help overcome feelings of loneliness?
- Research Question (RQ3): Do elderly people believe that the VR application can help to increase their levels of well-being?

5.1. Participants

Fifty volunteers participated in the experiment. To collect a sample of 50 users, we attended places frequented by the elderly, such as village squares, cafes, churches, rehabilitation centers, and nursing homes. The data collection process was not easy since it was a time-consuming process to find participants who were willing and able to perform the evaluation. For example, users with serious vision, hearing, and other related health problems were not able to participate in the process. Data collection lasted two months. Concerning the participants, 19 (38%) were males, and 31 (62%) were females. Regarding age distribution, 7 participants were 55–59 years old, 9 participants were 60–65 years old, 11 participants were 66–69 years old, 3 participants were 70–75 years old, and 20 participants were 79 years old and older. With regards to participants' occupation and mobility level, 76% of them were retired, and 28% had a mobility problem. Prior to taking part in the experiment, all participants were informed of the purpose of the study, and the experimental procedure was explained. Furthermore, the volunteers were informed of their right to withdraw their consent to participate in the study at any time. The experimental procedure received approval from the National Bioethics Committee, ensuring that all ethical considerations were considered during the experiment.

5.2. Methodology and Instruments

At the beginning of the experiment, the operator presented each volunteer with the research protocol. The protocol includes information on the purpose of the study, the headset installation procedure, and the VR immersion time. All participants were free to ask any questions they deemed necessary. Figure 5 shows users during the experimental evaluation procedure. For data collection, user observation, interviews, and questionnaires were used. The questionnaire consisted of three parts (parts A, B, and C) with closed-ended questions. Part A concerned mainly demographic data (gender, age, work status, and

physical mobility). Questions in Parts B and C of the questionnaire were based on existing loneliness [32], well-being [33], and usability [34] questionnaires. A number of questions from the aforementioned questionnaires were selected to create a customized questionnaire to suit the aim of the research experiment.

Figure 5. Sample of participants using the virtual reality application.

The first nine questions (see Table 1) of Parts B and C of the questionnaires were identical, so differences in responses before and after the intervention were quantified. In addition to the common questions, Part C of the questionnaire contained questions related to the attractiveness/usability of the application, the immersion levels of the users, and the overall impression of the users towards the application (see Table 2). Participant responses were on a 5-point Likert scale from "Strongly disagree = 1" to "Strongly agree = 5" with closed-type questions to enable grouping and analysis of results. At the beginning of the evaluation process, participants completed Parts A and B of the questionnaire, and afterwards they used the VR application for about 3–7 min. After the application trial, users completed Part C of the questionnaire. Then the researcher conducted an open-ended interview where users could elaborate on comments related to the application and ways to improve it. The total duration of the interviews ranged from 5 to 20 min. For the data analysis, the package SPSS was used. In the analysis, both descriptive and inferential statistics were applied to explore the differences among the groups, utilizing statistical tests, paired sample *t*-tests, and independent sample *t*-tests. During the analysis of the interviews, the phrases/keywords mentioned were grouped so that the opinions of the users could be quantified.

Table 1. The common questions from Parts B and C of the questionnaire presented to the users before (Part B) and after (Part C) the intervention.

Number	Question
B1/C1	Would I be interested in using a virtual reality application in my daily life to socialize with other people?
B2/C2	There are people I feel close to in the physical and/or virtual environment.
B3/C3	I feel alone.
B4/C4	There are people I can talk to in the physical and/or virtual environment.
B5/C5	I believe there are VR applications that help me not feel alone.
B6/C6	I feel healthy.
B7/C7	I have happy memories from the past.
B8/C8	I am very happy.
B9/C9	I am satisfied with everything in my life.

Table 2. The remaining questions from Part C of the questionnaire presented to the users after the intervention.

Number	Question
C10	I would like to use this app often.
C11	The app was easy to use.
C12	I thought I would need the support of a technical person to be able to use this app.
C13	The audio instructions were helpful in the application.
C14	Interaction in relation to site navigation was sufficient.
C15	I felt very confident using the app.
C16	I felt like I was in virtual space.
C17	When using the app, I still paid attention to the real environment.
C18	On a scale of 1 to 5 (1 = Poor app, 5 = Excellent app), I would rate the app with

5.3. Quantitative Results

A paired sample *t*-test before and after the intervention was used during the analysis. This test was used because the samples depended on the same person's responses in different circumstances (before and after the interference). The null hypothesis (H0) is that there is no significant statistical difference regarding the responses of the participants before and after the intervention, and the alternative (H1) is that there is a statistically significant difference with regard to the responses of the users before and after the intervention. Based on the results (see Table 3), there is a statistically significant difference with a *p*-value smaller than 0.05 for the pair of questions B5-C5: "I believe there are virtual reality applications that help me not feel alone". For the remaining pairs of questions, although there is a difference in the mean values, no statistically significant differences were recorded before and after the intervention.

Table 3. Mean and standard deviation of the mean number of participants (N = 50).

Question	All Participants		
	Mean	SD	*p* Value
B1	3.140	1.6164	0.537
C1	3.260	1.5493	
B2	4.200	1.3553	0.103
C2	4.280	1.3099	
B3	1.760	1.2707	0.569
C3	1.820	1.3045	
B4	4.380	1.0476	0.537
C4	4.320	1.0962	
B5	3.180	1.5996	0.000 *
C5	4.260	0.9858	
B6	3.640	1.3516	0.197
C6	3.780	1.4886	
B7	4.260	1.1031	0.293
C7	4.380	1.0280	
B8	4.160	1.0174	0.642
C8	4.200	0.9258	
B9	4.280	1.0506	0.533
C9	4.200	0.7825	

SD, standard deviation; * Statistically significant change (*p* value < 0.05).

The results of the non-parametric Wilcoxon Sign Rank Test before and after the intervention are presented. This test is used because the samples are paired and the data are on an ordinal scale since it has to do with the same person in different circumstances (before and after the intervention). Tables 4–6 show the results of the analysis for each group and the pairs of questions where statistically significant differences were observed. With reference to the results of the questionnaires, it was observed that in all the participants but

also in the results of each group only in question B5/C5, "I believe there are VR applications that help me not feel alone", there was a significant *p* value for all groups (see Table 3). We can justify this because people who used VR for the first time could realize the potential of using VR applications. It was observed that many users were willing to use the application if they had the necessary VR headset and smartphone equipment. A large percentage were positive about using a VR app, but not for everyday use. As observed in the age group of users older than 70 years, there is a significant *p* value of 0.022 for question B1/C1, "Would I be interested in using a virtual reality application in my daily life to socialize with other people?" and correspondingly, for question B5/C5, the *p* value is 0.000. This indicates that older people realize that virtual reality is useful as a means of enhancing socialization. Given that the proposed application is not a collaborative application, it is implied that the users considered the presence of a virtual audience as a step towards socialization. It was observed that people who did not have someone near them in their physical environment were more likely to use the app more often if they had the equipment. For question B6/C6, "I feel healthy", for the age group of 55–69 years, there was a significant *p* value of 0.035. This specific age group has the ability to socialize with colleagues and family; has mobility, meaning they have the ability to move for their needs; and has more direct contact with technology, meaning they are in better physical condition than the 70 and older group; hence, using virtual reality on a daily basis is not their priority. In question B9/C9, "I am satisfied with everything in my life", there was a significant *p* value of 0.049 in the non-disability group, with the difference in answers decreasing in the second part of the questionnaire. We believe this is justified because, after using the application, users reflected on the expectations they had set in the first part of the questionnaire, and as a result, they recalled memories from their young years, allowing them to temporarily forget about their age-related problems.

Table 4. Mean and standard deviation of the mean number of participants and the results of the non-parametric Wilcoxon Sign Rank Test with regard to the participants between groups 55–69 years and 70–79+ years old (N = 50).

Question	Group 55–69 Years			Group 70–79+ Years		
	Mean	**SD**	***p* Value**	**Mean**	**SD**	***p* Value**
B1	3.556	1.5525	0.501	2.652	1.5843	0.022 *
C1	3.370	1.3629		3.565	1.5616	
B2	4.741	0.8590	0.157	2.261	1.5141	0.317
C2	4.815	0.7863		3.826	1.2668	
B3	1.333	0.8321	0.180	2.565	1.5616	0.206
C3	1.222	0.5064		3.217	1.4446	
B4	4.852	0.4560	0.317	3.957	1.0651	1.000
C4	4.741	0.5257		3.783	0.9980	
B5	3.704	1.4627	0.033 *	3.913	1.2400	0.000 *
C5	4.185	1.1107		3.130	1.7659	
B6	4.000	1.1767	0.035 *	3.652	1.5258	0.951
C6	4.259	1.1959		2.522	1.5917	
B7	4.519	1.0874	0.157	3.826	1.3702	0.541
C7	4.593	1.0834		4.348	0.8317	
B8	4.481	0.9352	0.655	3.217	1.6225	0.405
C8	4.444	0.8473		4.130	0.9197	
B9	4.593	0.7473	0.206	3.913	0.9493	0.943
C9	4.444	0.6980		3.913	0.7928	

SD, standard deviation; * Statistically significant change (*p* value < 0.05).

Table 5. Mean and standard deviation of the mean number of participants and the results of the non-parametric Wilcoxon Sign Rank Test with regard to the participants between the non-retired and retired groups (N = 50).

Question	Non-Retired Group			Retired Group		
	Mean	**SD**	***p* Value**	**Mean**	**SD**	***p* Value**
B1	3.583	1.6214	0.457	3.000	1.6108	0.161
C1	3.250	1.2154		3.263	1.6552	
B2	5.000	0.0000	1.000	3.947	1.4695	0.102
C2	5.000	0.0000		4.053	1.4322	
B3	1.000	0.0000	1.000	2.000	1.3755	0.796
C3	1.000	0.0000		2.079	1.4023	
B4	5.000	0.0000	0.317	4.184	1.1355	0.712
C4	4.917	0.2887		4.132	1.1894	
B5	3.583	1.6214	0.025 *	3.053	1.5930	0.000 *
C5	4.417	0.9003		4.211	1.0176	
B6	4.583	0.5149	0. 083	3.342	1.4003	0.470
C6	4.833	0.3892		3.447	1.5544	
B7	4.667	0.4924	0.157	4.132	1.2119	0.541
C7	4.833	0.3892		4.237	1.1255	
B8	4.750	0.4523	0.157	3.974	1.0777	0.317
C8	4.583	0.5149		4.079	0.9968	
B9	4.917	0.2887	0.102	4.079	1.1242	0.839
C9	4.583	0.5149		4.079	0.8181	

SD, standard deviation; * Statistically significant change (*p* value < 0.0).

Table 6. Mean and standard deviation of the mean number of participants and the results of the non-parametric Wilcoxon Sign Rank Test with regard to the participants between the disability and non-disability groups (N = 50).

Question	Disability Group			Non-Disability Group		
	Mean	**SD**	***p* Value**	**Mean**	**SD**	***p* Value**
B1	2.929	1.5915	0.204	3.222	1.6408	0.931
C1	3.286	1.6375		3.250	1.5376	
B2	3.214	1.8051	0.317	4.583	0.9063	0.180
C2	3.286	1.8157		4.667	0.7928	
B3	2.214	1.5281	0.655	1.583	1.1307	1.000
C3	2.286	1.6375		1.639	1.1251	
B4	4.214	1.1217	0.096	4.444	1.0266	0.557
C4	3.857	1.3506		4.500	0.9411	
B5	2.786	1.6257	0.014 *	3.333	1.5856	0.000 *
C5	4.000	1.1767		4.361	.8993	
B6	2.357	1.1507	0.720	4.139	1.0731	0.096
C6	2.500	1.6053		4.278	1.1113	
B7	4.571	0.7559	0.083	4.139	1.1989	0.084
C7	4.357	0.7449		4.389	1.1283	
B8	3.500	1.2860	0.317	4.417	0.7700	0.739
C8	3.714	1.2044		4.389	0.7281	
B9	3.714	1.3828	0.276	4.500	0.8106	0.049*
C9	4.071	0.7300		4.250	0.8062	

SD, standard deviation; * Statistically significant change (*p* value < 0.05).

5.4. Qualitative Results

During the interviews/observations, participants expressed several interesting views regarding the application. There were participants whose recounting of their youthful memories evoked feelings of joy, nostalgia, and sadness. In particular, the oldest participant, who was 100 years old with excellent mental perception and vision, mentioned that such an application would make him forget the daily life of living in the rehabilitation house and felt a thrill to be able to see photos from his home town. There were also people who stated

that they would like to use this app frequently and would select different photographs every time they used it. It was also observed that some participants living in rehabilitation houses were reluctant towards virtual reality technology, as most of them did not have compatible smartphones and did not want to learn anything new about technology. Overall, based on user feedback, it seems that users were positive about their first contact with VR, and if they had the equipment, they would like to use it again.

For the analysis of the interviews, the most frequent keywords/phrases mentioned by the participants were registered (see Table 7). The most frequently mentioned phrase is "They don't feel lonely in everyday life (26/50 participants)". Hence, for most participants, it was not necessary to use the VR applications as a means of reducing loneliness. In particular, most people mentioned that, at their current age, they have family close to them (spouses, children, and grandchildren) and prefer to socialize with them instead of using virtual reality. The phrase "Useful for people who feel alone (21/50)" comes in second place, implying that although most users believe that it is not necessary for them to use the application, they realize the importance of the application for older people who live alone and do not have someone to talk to. Several positive keywords related to the application, such as "Easy to use" (18/50), "Nice Interface" (17/50), "VR Positive" (17/50), and "Immersion" (16/50), were registered, indicating the acceptance of the users towards the design and functionality of the application. Also, some users reported that they found the application enjoyable. Regarding the presence of the virtual audience, users stated that it encouraged them to engage in storytelling activities. Examples of negative keywords registered are "blurred vision" (15/50), which concerns both the quality of the equipment and the reduced vision of the participants due to age; "VR Negative (13/50)"; and "Not interested in VR (9/50)", where it was mostly from people who are not interested in using virtual reality since they prefer to socialize with their family members. Finally, the last keyword was "Feeling lonely (8/50)", where elderly people who may live in nursing homes or live alone reported feeling lonely and would like to have someone to talk to.

Table 7. The results of the most frequently positive and negative keywords/phases encountered.

		Keywords/Phrases	Participants
Positive	1.	VR Positive	17/50
	2.	Useful for people who feel alone	21/50
	3.	Easy to use	18/50
	4.	Immersion	16/50
	5.	Nice Interface	17/50
Negative	6.	VR Negative	13/50
	7.	Blurred vision	15/50
	8.	Not interested in VR	9/50
	9.	They don't feel lonely in everyday life	26/50
	10.	Feeling lonely	8/50

6. Discussion

According to the quantitative and qualitative self-reported results obtained by exposing elderly users to a memory-recalling storytelling VR application, it is observed that elderly users believe such an application can be useful for improving their overall wellbeing. Furthermore, users appreciated the ease of using the application as a result of the simplicity of the operation and the fact that no special equipment is required. Indicatively, elderly users reported that they do not need the support of another person to use the application, in contrast to other similar efforts [35] where the involvement of the whole family to assist elderly users in using a virtual application is required. Based on the research questions posed, the following conclusions are reached:

- Research Question (RQ1): Are elderly people willing to use the virtual reality application?

Based on both the qualitative and quantitative results, it was observed that the majority of the elderly users are willing to use the virtual reality application. This is especially true for the participant group of 70–79+ years, who mention that they would be interested in using a VR application in their daily lives to socialize with other people. However, a percentage of the users expressed their unwillingness to use the VR application due to their lack of knowledge of new technologies. We believe that if elderly people are provided with training on the use of new technologies, their acceptance of VR technology will increase.

- Research Question (RQ2): Do elderly people believe that the VR application can help overcome feelings of loneliness?

Elderly users believed that the specific application could indeed reduce their feelings of loneliness. In particular, they mentioned that through the application, they forget that they are in the real environment, which motivated them to start the narratives with a virtual audience. We believe that two characteristics of the application contributed to this observation. Firstly, the ability to enter a storytelling experience [36], and secondly, the presence of the virtual audience, which further motivated the users to start the storytelling according to the interviews. Since storytelling is among the favorite activities for elderly people [37], storytelling in a VR environment proved to be a suitable alternative when direct contact with a real audience is not feasible.

- Research Question (RQ3): Do elderly people believe that the VR application can help to increase their levels of well-being?

Most users had positive feelings during their use of the application. Overall, even the people who stated that it was not necessary for them to use the application at this stage of their lives said that it would be useful and enjoyable for people who feel alone as a means of escaping loneliness.

7. Conclusions and Future Work

The aim of the present research was to study whether older people believe that the proposed virtual reality application could help the elderly cope with feelings of loneliness and social isolation. Through the use of the application, the factors that influence how receptive users are to a new application were also studied. As a general picture, it can be noted that users are positive towards this technology but would like to use it only when they really need it, that is, when they feel lonely and would like to have someone to talk to.

In our future plans, we will rely on the needs of the users to improve the application. In particular, an important factor that most users suggest is having personal photos in the application and allowing the user to select the photographs to be displayed. In addition, the increased interaction of the virtual audience according to the narrative they receive from the user will be explored. Also, in the future, we plan to assess the quality of the storytelling provided by the user using dedicated presentation evaluation techniques [38]. Within this context, users could earn points based on the storytelling quality, so that a game-based, rewarding VR experience is offered. Also, the prospect of turning the application into an online collaborative that allows multiple users to discuss photographs and interact with each other will be explored.

A limitation of this work relates to the fact that the results were obtained based on self-reported data derived after a single session with each user. Experiments based on measurable indicators, such as the results of dedicated memory recall experiments, can provide more objective findings related to the effectiveness of the application. As part of our plans for future work, we plan to address this issue by staging repeated long-term experiments so that possible alterations in the mental abilities of elderly users participating in the experiment are registered using objective results obtained by established physiological tests [39,40]. We also plan to further validate the potential of the application for preventing problems associated with the mental abilities of elders. For this purpose, we are collaborating

with a nursing home so that the long-term experiments will allow for the assessment of the long-term impact of the application in relation to the mental abilities of elderly users.

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