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Immersive Virtual Reality App for Mild Cognitive Impairment

José Varela-Aldás[1a,1b], Guillermo Palacios-Navarro[2], Iván García-Magariño[3]

josevarela@uti.edu.ec, guillermo.palacios@unizar.es, igarciam@ucm.es

[1a] Universidad Tecnológica Indoamérica, 180103, Ambato, Ecuador.

[1b,2] University of Zaragoza, 44003, Teruel, Spain.

[3] Complutense University of Madrid, 28040, Madrid, Spain

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Abstract: A characteristic symptom of neurodegenerative diseases is the deterioration of the memory. These problems usually worsen with the progression of the disease, being the cognitive rehabilitation an important tool in order to slow down the progress of the disease in the patient. This work presents the development of a mobile virtual reality application through a serious game to boost the memory by solving mazes in three levels of difficulty. The application uses the Gear VR glasses to provide the user with an immersive experience. The results present the proposed application, showing the components of the virtual environment.

Keywords: virtual reality; mobile application; immersive environment; memory deterioration.

1. Introduction

Memory loss is the main symptom of multiple neurodegenerative diseases (Parkinson's, Alzheimer's, sclerosis, and so on). These diseases currently have no cure, but there are several treatments to slow down their progress, allowing to prolong life and improve the patient's living conditions. The traditional treatments include brushing up on activities and exercising the brain, for which the assistance of qualified personnel and continuous rehabilitation sections are required, however, the use of technology has changed the methodology used to stay mentally sharp (Wang & Holsinger, 2018).

With the rapid development of new information and communication technologies, currently, new prospects for assistance in the healthcare sector have been inserted. Specifically in assisting cognitive rehabilitation therapies, virtual reality (VR) environments have been developed in a way which allows the patient to train their memory in serious game applications with multiple alternatives of use. At a basic level, virtual environments are presented on screens and manipulated using external tactile inputs, but at an immersive level, the system has head-mounted displays (HMDs), which allow the user to interact realistically with the game (Chicaiza et al., 2018). However, an inherent limitation of this technology is the high costs of specialized equipment which rehabilitation would require.

A sector with more technological improvements are the Smartphones, which currently have more processing features and improved accuracy in their sensors than ever before, so it is not a problem to implement VR applications in these devices, and with the support of low-cost components, smartphones can be used as portable HMDs, where the device's screen shows the virtual environment to the user (Zhang & Ho, 2017). This technological combination facilitates the use of cognitive virtual rehabilitation in patients with neurodegenerative diseases, without the need of leaving their home.

In this work, a serious game of virtual reality is presented to train the memory of patients with neurodegenerative diseases in its early stages. The main purpose of the proposed application is to generate a computer created environment for the patient to solve a labyrinth in three degrees of difficulty, previously reviewing the possible solutions from an aerial view. This application is implemented on a mobile device, where Samsung Gear VRs are used to obtain the immersion effect; an operation evaluation is performed and a SUS usability test is applied to the user. This paper is structured as follows: In Section 2, a review of the state of the art is given; In Section 3, the design and implementation of the proposed application are described. In Section 4, the experimental results are described. Finally, in Section 5, conclusions are established and future work is outlined.

2. State of the art

Currently, virtual reality is a widely applied tool in multiple areas. In this context, its characteristics have been studied and the user's reactions have been compared with respect to real experience. (Raptis, Fidas & Avouris, 2018) studies the effects of a fictitious reality in tourism and recognizes its advantages, the results support the importance of these systems; (Ding, Zhou & Fung, 2018) finds that enjoying cinema in VR exceeds typical 2D entertainment. On the other hand, a field which makes the most of virtualization technology is health, developing systems with virtual elements in the rehabilitation of various diseases. (Lv et al., 2017) designs a serious game for the rehabilitation of Dysphonia, and tests with experts and patients support the use of the voice game; (Arango, Mazo & Peñapalacio, 2013) implements an augmented reality system to treat phantom limb syndrome; and (Wang & Reid, 2013) uses a VR application to improve contextual processing in children with autism where cognitive flexibility was demonstrated.

A specific case of the use of information technologies in health is the treatment of neurodegenerative diseases, for which applications have been developed which slow down the decline in memory (Jonsdottir et al., 2018; Zanier et al., 2018), show that these symptoms are found in patients with diseases such as Alzheimer's, multiple sclerosis, Parkinson's, Huntington's, and so on, but they also manifest due to aging in older adults (Chicaiza et al., 2018) demonstrates experimental results of a complex system of virtual reality implemented which favors the exercise of memory. The use of these VR applications is usually accompanied by an examiner who monitors the progression of the disease, but in cases of mild cognitive impairment the user might perform their virtual rehabilitation from home, facilitating the treatment of the disease.

The insertion of technological systems to support rehabilitation usually involves high costs, because they require up-to-date technology and specialized software, being the use of mobile devices a solution to this problem; (Razo Salas, Vázquez Reyes & Solís

Robles, 2016) uses the screen of a mobile device to visualize the images in an endoscopic process, results which are approved by a specialist; (Green et al., 2018) proposes a mobile application to assist in the providing of anesthesia; similarly, cognitive problems can be supported by mobile applications, (Yasini & Marchand, 2016) analyses the use of a smartphone in the cognitive stimulation of older adults and the results indicate that users do not get tired of playing with their tablet over time and that the average daily time spent on games increases significantly. Furthermore, combining mobile devices with virtual reality, involves several elements for its operation; (Zhang & Ho, 2017) analyses the use of immersive mobile applications for the rehabilitation of addictions through a Smartphone and an HMD device, concluding the benefits of the appropriate use of mobile virtual reality in this area of health.

3. Proposed system

The proposed structure involves several components to support the virtual rehabilitation system. To facilitate the usability of the system, the proposal has been designed considering the installation costs, the requirements of the workplace, and the difficulty of operation. The system consists of a virtual reality environment which allows exercising the memory of the patient in different levels of difficulty. In order to achieve a certain level of immersion, portable HMDs are used to support the visualization of the application from virtual reality glasses for Smartphone, where the environment is controlled by the user from a manual command. The components of the system are described in the following sentences.

Figure 1 presents the proposed system for the cognitive rehabilitation of patients with memory impairment. At this point, the user uses two devices to interact with the rehabilitation system: Gear VR headset is used to achieve the player's immersion in the virtual environment as an HMD device, allowing the user to look at the environment and control the visualization through the movements of the head and the hand controller. This allows the patient to navigate in the virtual environment and select the options of the application. On the other hand, the Smartphone is the most important element of the system because it performs the processing of the aforementioned devices, the virtual reality application processes, the data corresponding to the Gear VR, and the hand controller.

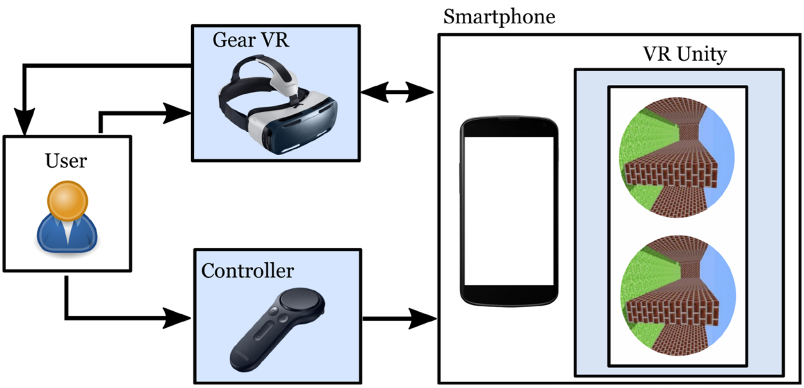

Figure 1 – Mobile virtual reality system

The application of the virtual environment allows the patient to exercise their memory by solving mazes in 3 levels of difficulty. Figure 2 shows a summary of the proposed application, where the main menu contains the access button to the application, then the patient must perform the user identification to load their previous data. The secondary menu allows the user to select the difficulty level and display the previous ratings using the stored data. Within the game, the user can firstly see an aerial view to perform the selected memory exercise, reviewing the possible exit routes of the maze and then he/she is positioned somewhere in the maze. The next instruction is to try to get out of the maze, reminding the shapes previously displayed. Once achieved the objective, the application presents the results of the experiment and this information is stored in a database; the user can continue with the game experiments or exit if desired. For a better understanding of the components of the application, the following section describes the elements of the Virtual Reality application.

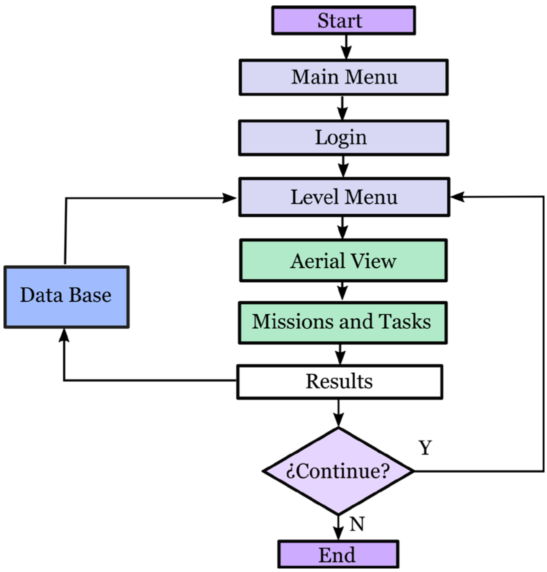

Figure 2 – Proposed application

4. Development of the application

The virtual reality application has been developed in unity due to the flexibility in the selection of hardware, allowing to install the application on a Smartphone to use it as an HMD device. Figure 3 presents the components of the virtual system, where the three main components can be differentiated: The Game Objects, which includes all the elements that make up the virtual environment; the virtual reality, which coordinates between the virtual environment and the devices for interaction with the user; and the database, which stores the information related to the features of the game and the results of the users.

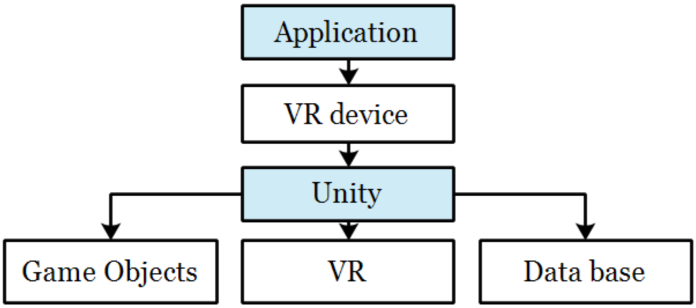

Figure 3 – Application components

4.1. Virtual environment

The virtual environment is made up of three-dimensional elements which have been developed in different support platforms. Figure 4 shows the three stages for the creation of virtual objects.

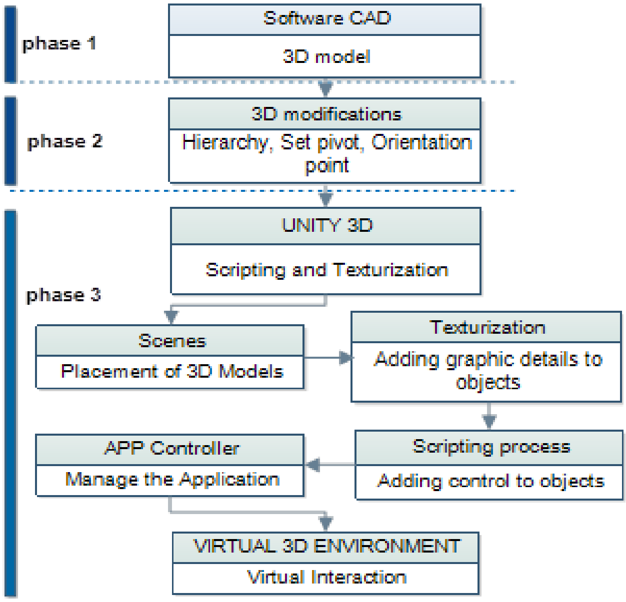

Figure 4 – Development of the virtual environment

In a first phase it is necessary to build the solid objects in a CAD software which allows developing the 3D models; later, these models require changes in their characteristics, such as the creation of hierarchies and the establishment of points of orientation. Finally, these files are exported to unity to be textured and used in virtual reality scripts. The new objects placed in unity need modifications to be used in the virtual reality application, starting with the construction of scenes through the location of the exported models. Additionally, details are added to the graphics by applying textures to the objects, these components are controlled by scripts to fulfill their function in the virtual reality application. These functionalities are evaluated and corrected in a process of validation of scripts, finally, the user interface for user interaction with virtual scenes is developed.

The serious game is developed to exercise short-term memory in the user. This rehabilitation tool allows the user to memorize details of the environment and to provide ways to move in computer-generated environments. The main activity is to solve a maze which is initially visualized from an aerial view, allowing the user to find an exit route. Once inside the maze, geometric shapes are presented in order to increase the difficulty of the application. The exercise can be done in three levels of difficulty, as shown in Figure 5; the basic level requires finding the exit in a small maze and counting the number of geometric shapes which appear in the path; the medium level consists of solving a moderately complicated maze and memorizing the number of geometric shapes, each shape with a specific color; and the advanced level requires getting out a complex maze, remembering each of the geometric shapes with their respective color.

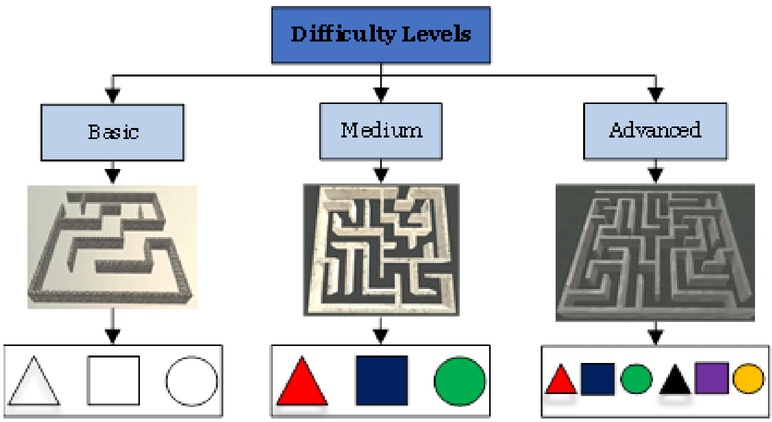

Figure 5 – Levels of difficulty

4.2. Virtual reality features

The virtual reality feature is integrated by the locomotion of the player, the interaction of the user with the virtual environment, and the user interface.

Locomotion

The movements on the virtual environment are developed using the smooth artificial locomotion technique which allows the user to move slightly in the desired directions by moving the thumb on the touchpad of the controller, as shown in Figure 6. This technique of locomotion is useful to move in small spaces and inserts realism to the displacements and avoids confusions of spatial orientation as opposed to the teleport method. The allowed movements are a linear forward and backward speed and angular velocity with fixed rotation step to prevent motion sickness, both movement options controlled from the controller's touchpad.

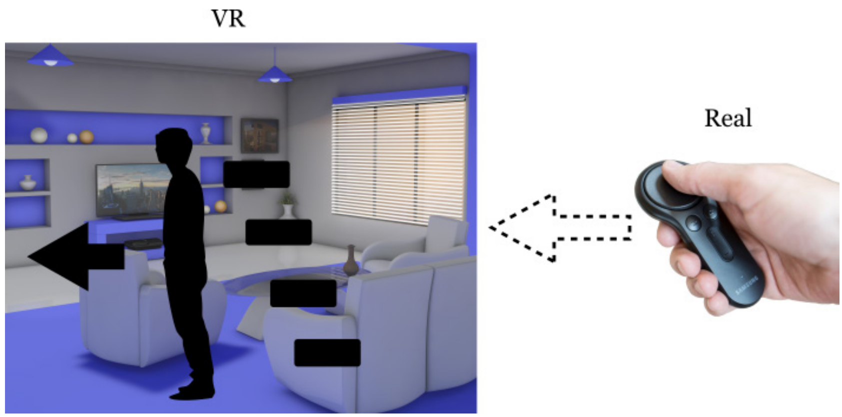

Figure 6 – Smooth artificial locomotion

Interaction

For the user to interact with the virtual environment in an immersive way, the Smartphone manages the images to be viewed according to the user's head movement, this is possible due to the smartphone's inertial sensors, achieving greater realism and comfort in the VR. The Gear VR controller also includes an inertial measurement unit, which allows addressing a pointer in the virtual environment with 2 degrees of freedom, as shown in Figure 7. In addition, the selection of options is executed by a trigger button.

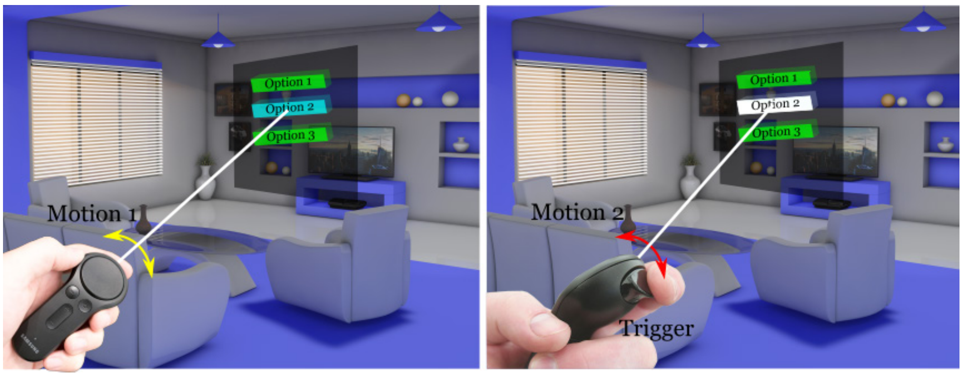

Figure 7 –Virtual interaction

User Interface

The VR application has three interface panels to choose, Figure 8 lists these components. Initially, the user must log in to the system using a username and password, this data allows retrieving the information of the user profile and remember the achievements. The next panel is used to select the level of difficulty to solve, loading the system according to the user's selection. Finally, the results panel presents the scores reached at the end of each cycle.

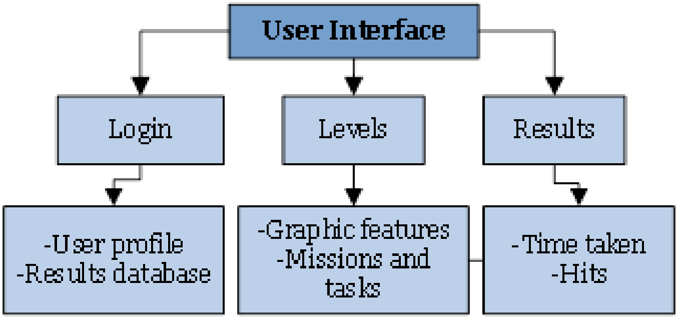

Figure 8 – User interface components

4.3. Database

The VR application has a database which stores the information in three blocks, as shown in Figure 9. The user block saves the data for access to the application and the profile of the users registered in the system. The information of the missions contains the mazes for the three levels of difficulty, stores the geometric shapes, the tasks to be done in the path of the mazes, and finally the results, where the time histories and successes obtained at the end of each game are recorded.

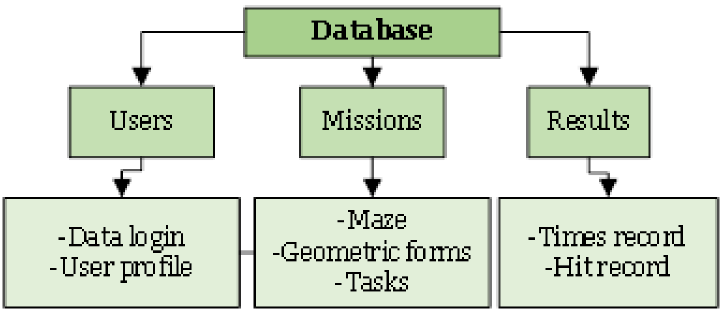

Figure 9 – Database

5. Experimental results

For the experimentation of the immersive virtual reality mobile application, an example is presented in this Section. For this, a Galaxy S8+ Smartphone and the Gear VR headset with its controller has been used, where Figure 10 shows the experiments carried out with a male user of 60 years of age. In this example, the user is healthy but presents some memory difficulties produced by age.

Figure 10 – Experiments on GearVR device

When started the game, the user must log in with their email and password, as shown in Figure 11. In case of not being registered, a new user profile must be created with the personal data.

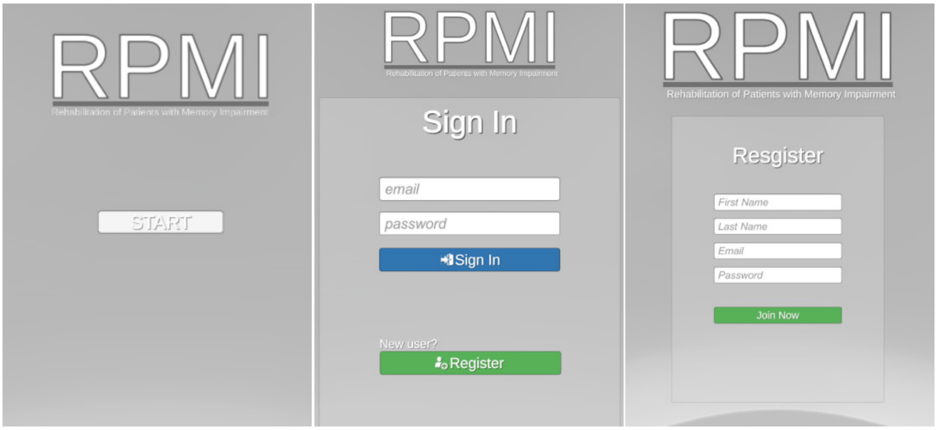

Figure 11 – Login to the application

Then choose the level of difficulty to be evaluated. Figure 12 presents the three levels to solve in maze.

Figure 13 shows the first view of the maze to be solved from an aerial view. This allows the user to analyze the exit routes for later move inside the maze, and then he/she is located at the entrance of the route.

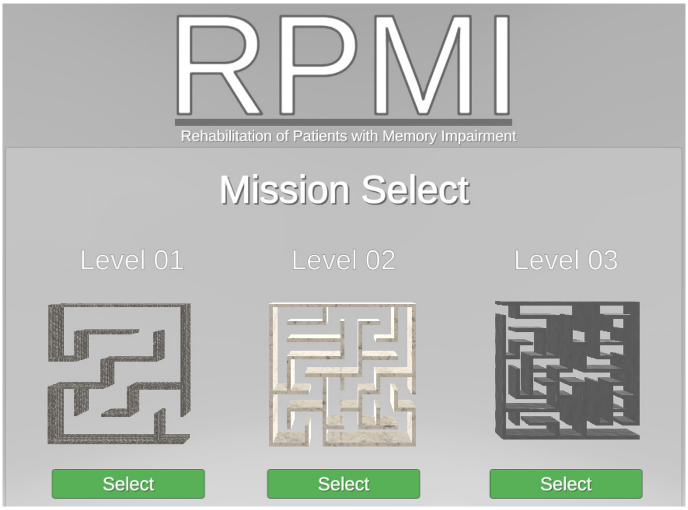

Figure 12 – Interface to choose the level of difficulty

Figure 13 – Starting the game

Figure 14 – Inside the maze

Once inside the maze, the users must move in the directions which they consider correct using the touchpad of the Gear VR controller. In the path, the user will find geometric figures according to the level selections, see Figure 14.

At the end of the maze, a questionnaire appears which records the geometric shapes remembered and assigns a score according to the user's responses. These data are stored and summarized in the results screen of Figure 15, where the user registers 5 days of experiments, he/she have solved the maze in the three levels of difficulty, and an improvement in the score reached is observed, as well as in the time taken to find the exit.

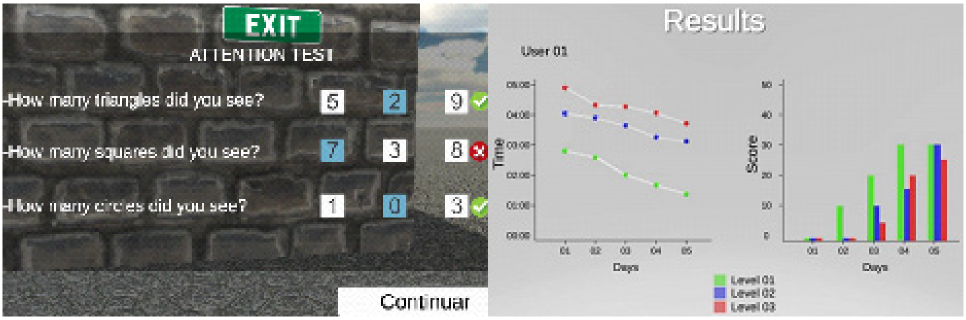

Figure 15 – Results

N°	Questions	Score	Operation
1	*I think I would like to use this system frequently*	4	4-1=3
2	***I find this system unnecessarily complex***	**1**	**5-1=4**
3	*I think the system is easy to use*	5	5-1=4
4	***I think you would need technical support to make use of the system***	**1**	**5-1=4**
5	*I find the various functions of the system quite well integrated*	4	4-1=3
6	***I have found too much inconsistency in this system***	**1**	**5-1=4**
7	*I think most people would learn to make use of the system quickly*	5	5-1=4
8	***I found the system quite uncomfortable to use***	**3**	**5-3=2**
9	*I have felt very safe using the system*	3	3-1=2
10	***I would need to learn a lot of things before I can manage the system***	**1**	**5-1=4**
	TOTAL		34
	Global Value		**85**

Table 1 – Survey results

Additionally, Literature of (Sauro & Lewis, 2011) and (Shaheen & Rehman, 2018) is used to determine the usability of the application by means of a SUS test. The score is determined by the sum of the values of each item, said score will have a range of 0 to 4. For numbers 1, 3, 5, 7 and 9, the operation is the score given minus 1; for items 2, 4, 6, 8 and 10, the operation is 5 minus the score. The total sum of the results is multiplied by 2.5 obtaining the overall value of the SUS. The final result is obtained in the range of 0 to 100. For the answers indicated in the questions, Table 1 is obtained.

The results of this example indicate that the application works correctly and provides a user-friendly experience in the test performed, however, it also shows an opportunity for improvement in some questions of the SUS, especially in providing security to user.

6. Conclusions

Modern mobile devices support immersive virtual reality applications, this because of their high throughput and multiple sensors. Specifically, cognitive virtual rehabilitation allows the user to treat the progress of a neurodegenerative disease in its early stages. This implies which mild memory impairment can be treated by memory exercises in virtual environments.

This application supports the user to train their memory through a maze-solving game in an immersive way using the Gear VR, allowing the user to remember an aerial view of the routes and to practice the spatial orientation in the virtual environment. In addition, the patient might memorize geometric shapes which must be remembered at the end of the maze. The results show that the user performs many successful tests with improvements in their memory retention scores, and an acceptable usability score.

Future work is intended to include more experiences in the process of navigate through the maze and include biometric sensors in the user to monitor the patient's vital and cognitive states.

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