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Development of a Mobile Virtual Reality Application based on Morris Water Maze for the Evaluation of Spatial Memory in Human Beings

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Abstract. Remembering and learning are important activities for the brain; Spatial memory is related to the capability to acquire and hold associations about what is in the environment. Unfortunately, some factors such as age, drugs, and mental illnesses, among others, lead to the loss of the ability to remember things or events that occur in people's lives, including spatial memory. There are several tests (Such as radial arm maze task, geometric arena task, and Morris water maze) generally used to evaluate spatial memory in rats and animals. Still, there are not so many tests applicable to human beings. Several researchers have discovered that virtual reality could help with these types of problems. People can be immersed in a virtual world and solve aspects of space. One of the advantages of virtual reality is that people can be analyzed in safe environments. This work presents the development of a mobile application capable of evaluating spatial memory in humans through virtual reality; Taking the bases of the Morris Water Maze. The goal of this application is to have an alternative test to evaluate spatial memory with low-cost and ecological materials, virtual reality, and the advantages of mobile applications. As a pilot test, the application was tested on 18 young students who demonstrated the use of their spatial memory within the application.

Keywords: Mobile application, Morris water maze, spatial memory, virtual reality.

1 Introduction and Related Work

1.1 Virtual Reality

Virtual reality (VR) is becoming relevant due to its capacity to recreate some of the characteristics of the real world and its interactions. This is achieved through computer graphics, visual displays, and input/output devices.

This article considers VR as a system and technology that allows the simulation of reality in a three-dimensional environment through a computer and where all of its elements are synthetic, with the advantage of interacting in real time with them. [1, 2, 3].

VR generally works with the following four components: 1) A computer or hardware. 2) A device to display the virtual world can be a Head-Mounted Display (HMD). 3) The virtual world (software). 4). Input devices (such as keyboards, mouse, and gamepad controllers). [1, 2, 3].

This project uses a smartphone and a Google Cardboard for the HMD, Unity Game Engine as the program to create the virtual world, and a PlayStation 4 controller as an input device. One of the most powerful advantages of VR is that people do not have to be submitted to physical tests to collect behavioral data. Therefore, VR, as a tool for medical and psychological purposes, has grown. Different studies have been carried out to treat mental illnesses like anxiety, spatial memory, and fears. [4, 5, 6].

Some studies have shown that the response to various situations in our environment is similar to what happens in virtual worlds; people can react with fear, alertness, happiness or relaxation depending on the virtual environment to which the person was subjected. VR is useful for evaluating and treating mental illnesses. [7, 8].

1.2 Spatial Memory

Learning and spatial memory are related to the capability to acquire and maintain associations of what is around, allowing the correct function of the organism in his environment.

Spatial memory consists of multiple specialized mechanisms for encoding, storing, and retrieving information about routes as well as spatial locations. Furthermore, it is known from studies that the hippocampus plays a crucial role in this part of memory [9, 10].

“Humans navigate complex environments effectively by identifying and monitoring environmental spatial cues” [11].

The ability to navigate within a physical space is one of the first functions to suffer from cognitive decline over the years (as in Alzheimer’s disease). Therefore, a crucial intervention in the early stages is essential. One critical problem in determining a mental illness is its high cost, and that is difficult to say when a person is having a considerable decline in their spatial memory, [12, 13].

1.3 Morris Water Maze

There are several techniques and tests (such as radial arm maze task and geometric arena task) to determine several parameters (solving speed, path or route, final distance, latency) of spatial memory. One of the most used is the Morris water maze (MWM), this test was originally adapted for rats, where they have to learn and memorize the position of the escape platform located inside a pool (ideal for the test) and with the relation of different visual clues. [14].

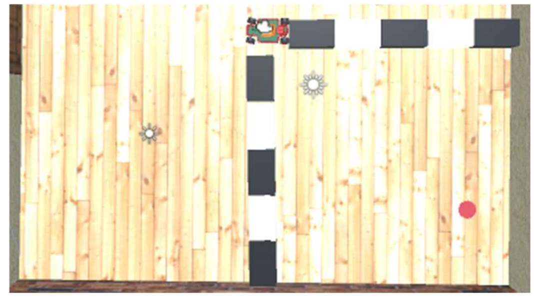

Fig 1. Size of the virtual environment

Fig 2. Position of visual clues in the virtual environment

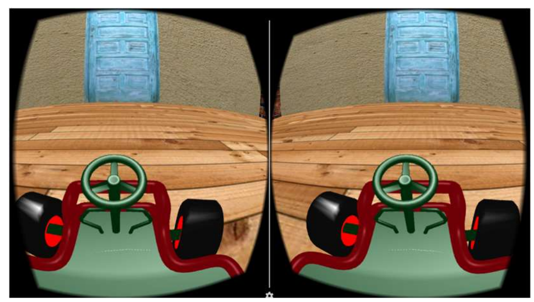

Fig 3. User’s view

MWM is a procedure for spatial memory in rats, where they have to swim and learn how to escape from turbid water through a hidden platform inside the swimming pool.

Rats are placed inside any point of the pool; they swim through it, trying to find the hidden platform. Usually, when they finally find the platform, they learn its position, and from there, they can find it swimming from any point in the pool.

The precision of direction, timing, and other measurements can show if rats are learning from their space. The comparison with other rats that have brain damage can show another perspective for spatial memory and neuroscience.

The pool, in general, is circular, with temperatures from 25°C to 28°C [15].

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Fig 4. Track of movements

1.4 VR Application for the Evaluation of Spatial Memory

This work considers the three research areas mentioned above for the development of the virtual reality application (VR, spatial memory, and MWM). Virtual reality was chosen due to its immersive capacity in virtual environments, which favored a more realistic reaction from the user. MWM is strongly linked to the evaluation of spatial memory and is one of the most used techniques in the evaluation of spatial behavior in animals.

Therefore, this work presents the development, design, and pilot test of a mobile application to evaluate spatial memory in humans (focusing mainly on the MWM) and using VR, so that it can be used in subsequent tests within the medical, psychological and neurological branches. The application was tested on 18 young students who demonstrated their spatial memory capacity using the application.

2 Design and Development of a VR Application to Evaluate Spatial Memory

To develop the application based on the MWM the next two key elements are considered: 1) development platform. 2) HMD, due to its ability to cover the eyes of the user and make him be part of the virtual world.

The development platform is essential to get an application in a short time; in this work is considered to use an engine that improves the timeline of development for the application; there are several engines such as Unreal Engine, Torque, and Unity. This project uses Unity for its documentation, develop community, its capability to be cross-platform (including mobile platforms as IOS or Android), its cost and because it can be used with VR. [16, 17].

Considering the use of HMD, five different options were analyzed: HTC Vive from HTC, Oculus Rift from Facebook, Sony PlayStation VR from PlayStation, Gear VR from Samsung, and Google Cardboard from Google. This project uses Google cardboard because of its low price and compatibility with Unity.

The first point to consider in the development of the VR application was the maze; A virtual environment like MWM with three clues and one platform was designed considering the idea of other authors (as in some MWM tests in animals). These visual clues are used in the virtual MWM to guide the user through the world, no matter where the user starts the tests. The perspective of the user is in first person (as if the user were in the maze) [14].

The next step was to think about the approximate size of the virtual world. The size of the swimming pool in experiments with rats was of 1.32 meters of diameter, with a height of 0.40 or 0.60 meters. The average size of a rat is between 32 and 46 centimeters without the tail; it can measure from 17 to 25 centimeters long.

This gives a length of 29 centimeters without the tail so that an average rat could be around six times smaller than the diameter of the swimming pool. In figure 1, a proportional size for the virtual environment with at least five times the size of the user (in the virtual environment) was designed [14, 18].

In this case, the user will be the car that is in the middle of the virtual world. The white and black squares on the sides of the car show how big the environment is (5 times bigger). The red circle on the floor corresponds to the hidden platform for the user. Clues guide the user to the platform no matter if they start in the same position or not.

Figure 2 shows how the different clues are positioned in the virtual world: Brick wall on the left: Forest Painting[1], the Brick wall on the right: Ocean

[1] Source: fondos.wallpaperstock.net

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Table 1. Multivariate contrasts in latency, time and distance

		Value	F	Gl (Hypothesis)	Gl (Error)	Sig.
Latency*Group	Pillai's Trace	.419	1.08	6.000	9.000	.440
	Wilk's Lambda	.581	1.08	6.000	9.000	.440
	Hotelling's Trace	.720	1.08	6.000	9.000	.440
	Roy's Largest Root	.720	1.08	6.000	9.000	.440
Time*Group	Pillai's Trace	.479	1.37	6.000	9.000	.320
	Wilk's Lambda	.521	1.37	6.000	9.000	.320
	Hotelling's Trace	.918	1.37	6.000	9.000	.320
	Roy's Largest Root	.918	1.37	6.000	9.000	.320
Distance*Group	Pillai's Trace	.285	.597	6.000	9.000	.727
	Wilk's Lambda	.715	.597	6.000	9.000	.727
	Hotelling's Trace	.398	.597	6.000	9.000	.727
	Roy's Largest Root	.398	.597	6.000	9.000	.727

Painting[2], Front wall: Wood Door[3], Rear wall: Without a visual clue.

The next image (figure 3) will represent what the user sees (each image corresponds to the left and right eye). The user will be capable of spinning his or her head to the right, left, up, or down, to look whatever he or she wants, so to take the necessary reference of his or her visual space and start to use spatial memory.

This project uses a PlayStation 4 controller for movement in the virtual environment because of its straightforward implementation in the project and compatibility with Unity.

The motion was tracked like in MWM (creating a path of movement), as in figure 4. The application generates a line with the path of the user, and in the end, records the final distance.

The data that the VR application collects from the user for further analysis are: (1) **Latency:** Latency was defined in this project as the period it takes for the users to think about where they are and start moving through the virtual space. (2) **Time:** This is the final time that users require from the beginning of the test to the end (when they finally find and touch the platform). (3) **Distance:** It is taken from the path that the user makes across the virtual environment. The distance and path can be seen from the tracking line (as in figure 4). The measurement will be in meters.

3 Tests and Experimentation

Seven tests were designed to evaluate the user's spatial memory within the mobile application. This, considering the following protocols (1) *reference memory protocol*, this is about the hidden platform; (2) *reversal protocol*, change the position of the platform; (3) *delayed matching to place protocol* where distance and time variables are used [15].

Test 1: Recognition test for helping the user to learn and control movement, virtual space and understand what it needs to do (find the platform) and recognize the surroundings in order to make spatial memory activities. This test was designed to place the user in the center of the virtual world, and the escape platform in the lower-left corner.

Test 2: The same as the first test, but this time the user must recognize the space immediately and reach to the platform faster and with a shorter path.

Test 3: The platform is in the same place, but the initial position of the user changed to the lower

[2] Source: es.hdlandscapewallpaper.com

[3] Source: www.puertascamino.com

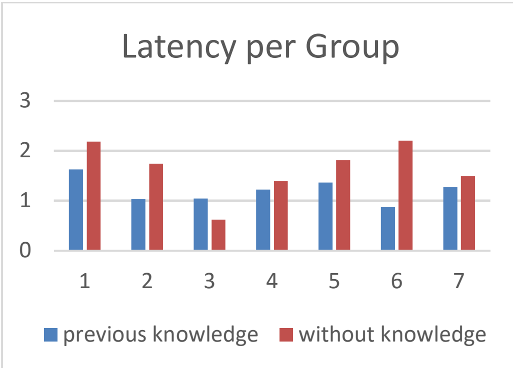

Fig 5. Analysis of descriptive data (Latency)

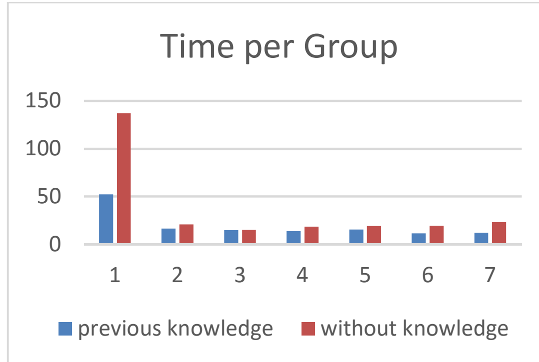

Fig. 6. Analysis of descriptive data (Time)

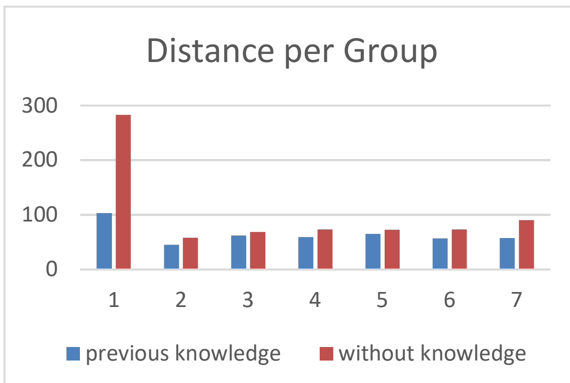

Fig 7. Analysis of descriptive data (Distance)

right corner. This forces the user to take a different path to the goal.

Test 4: As in experiment three, the user should keep the parameters (Latency, Distance, and Time) from the three previous tests.

Test 5: This test remains with the same position for the user but changes the platform position to the upper left corner in the virtual world. This is a special test as it introduces a flashing light element in two of the corners. This element presents a distraction to the user.

Test 6: This test is the same as in test 5; the user should keep the parameters (latency, Distance, and Time).

Test 7: This test keeps all the parameters of the previous test but with no flashing lights. It is expected that the user reaches the platform quickly and with an efficient path.

3.1 Participants and Procedure

For the experimental section of the project, an agreement was reached with a high school in the city of Guadalajara, Jalisco, México (High School number 40 José Clemente Orozco). The tests were applied to 18 high school students, nine boys, and nine girls.

They were only told how to control their movements in the virtual environment with the PS4 controller and what was the objective for all the tests.

The test was applied in a laboratory inside the high school. Also, we decided to choose a group of students with previous knowledge in video games and another group without any knowledge; in this way, make a comparison between them. There were ten students with prior experience and eight without expertise.

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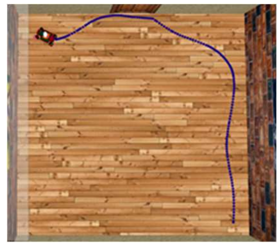
Table 2. Comparison between two students

Test 1 – Student A Latency: 3.98 Time: 26.0 Distance: 59.5	**Test 1 – Student B** Latency:1.54 Time: 33.45 Distance: 106.39	**Test 7 – Student A** Latency:0.44 Time: 11.08 Distance: 61.23	**Test 7 – Student B** Latency:0.56 Time: 8.45 Distance: 53.94
			

4 Results and Discussion

To test the application and evaluate its effectiveness in the spatial memory tests with humans, an analysis of variance (ANOVA) was carried out to determine if there were differences between the group of prior experience versus the group without expertise.

This was done using an adjusted probability level of 0.05 in the variables of distance, time, and latency provided by the application after each of the seven tests for both groups of students.

As shown in Table 1, no statistically significant differences were found in any of the three variables by group after the ANOVA analysis. The next thing was to determine if the students had memorized the virtual environment and had learned from it. An analysis of means was carried out for each of the seven tests in both groups of students.

The first test (recognition test) was the most complicated for both groups. In this test, the maximum values for the three variables (Latency, Time and Distance) were obtained. However, during the next six trials, the participants started to take shorter routes (shortening their distances).

They improved their total time to finish each of the tests despite changing them of place within the virtual environment or introducing the element of flashing light (see figures 6 and 7).

During the first four tests, the tendency in the latency variable was to decrease as participants became more accustomed to the virtual environment and made decisions more quickly. However, tests 5 and 6 (where the flashing light is introduced) reveal that the latency increases again, which indicates that the participants were distracted due to the light, increasing their reaction time (latency) (see fig. 5).

However, their distances and total times did not change. Throughout the whole procedure applied to the students was not detected either anomaly that could block the performance of the students. The VR application worked correctly in displaying the virtual world and in the collection of the user data.

Table 2 shows the first and final test of one of the best students in terms of performance in the application (student A) and in terms of previous expertise, in front one with the lowest results (student B) and without knowledge in games. In table 2, at the end of the tests, both participants had memorized the environment (virtual space), and they were close to each other in their performance.

It was just at the beginning where the participant A stayed ahead in terms of performance. All the participants memorized the virtual environment, and with every test, they improved their times and distances. In the end, both groups were close.

In several other studies, similar findings have been reported. Their research revealed that participants were able to enhance their spatial memory, resulting in improved performance in terms of both time and distance. For instance, the significance of virtual environments as a valuable tool for studying spatial memory in humans has been underscored [10, 12, 19, 20, 21].

5 Conclusions and Future Work

This work has presented the development and pilot test of a mobile virtual reality application for the evaluation of spatial memory. Seven tests were designed to change the conditions of the virtual environment for the participants and to cover several MWM protocols in a single mobile application.

The implementation of a virtual reality environment based on the Morris Water Maze made it possible for participants to use their spatial memory within a controlled space (besides some distractions to the environment were introduced in some of the tests) and be evaluated according to their performance in terms of three main variables (time, latency, and distance).

The mobile application introduced in this study represents a promising resource for professionals in the fields of medicine, neuroscience, and psychology, particularly those seeking tools for assessing human spatial behavior.

We assert that by employing applications like the one presented in this work, researchers can obtain results through secure, highly accurate and ecological methods, all while enjoying the convenience of a mobile application that can be readily accessed on a smartphone.

Future work will confirm the designed tasks using standardized neuropsychological methods. In addition, The VR application will be enhanced for future investigations in different opportunity areas; some techniques of serious games and gamification would be added to motivate people to use the application and then use their data in future research.

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References

1. **Rothbaum, B. O., Hodges, L. F., Kooper, R., Opdyke, D., Williford, J. S., North, M. (1995).** Virtual reality graded exposure in the treatment of acrophobia: A case report. Behavior therapy, Vol. 26, No. 3, pp. 547–554. DOI: 10.1016/S0005-7894(05)80100-5.
2. **Ma, M., Zheng, H. (2011).** Virtual reality and serious games in healthcare. Advanced computational intelligence paradigms in healthcare 6. Virtual reality in psychotherapy, rehabilitation, and assessment, Vol. 337, pp. 169–192. DOI: 10.1007/978-3-642-17824-5_9.
3. **Roda-Segarra, J., Mengual-Andrés, S., Martínez-Roig, R. (2022).** Using virtual reality in education: a bibliometric analysis. Campus Virtuales, Vol. 11, No. 1, pp. 153–165. DOI: 10. 54988/cv.2022.1.1006.
4. **Srivastava, K., Das, R. C., Chaudhury, S. (2014).** Virtual reality applications in mental health: Challenges and perspectives. Industrial psychiatry journal, Vol. 23, No. 2, pp. 83–85. DOI: 10.4103/0972-6748.151666.
5. **Annett, M. K., Bischof, W. F. (2010).** Investigating the application of virtual reality systems to psychology and cognitive neuroscience research. Presence: Teleoperators and Virtual Environments, Vol. 19, No. 2, pp. 131–141. DOI: 10.1162/ pres.19.2.131.
6. **Abd-Alrazaq, A., Alhuwail, D., Al-Jafar, E., Ahmed, A., Shuweihdi, F., Reagu, S. M., Househ, M. (2022).** The effectiveness of serious games in improving memory among older adults with cognitive impairment: systematic review and meta-analysis. JMIR serious games, Vol. 10, No. 3. DOI: 10.21 96/35202.
7. **Michael, D. R., Chen, S. L. (2005).** Serious games: Games that educate, train, and inform. Muska & Lipman/Premier-Trade.

8. **Dehn, L. B., Piefke, M., Toepper, M., Kohsik, A., Rogalewski, A., Dyck, E., Schäbitz, W. R. (2020).** Cognitive training in an everyday-like virtual reality enhances visual-spatial memory capacities in stroke survivors with visual field defects. Topics in Stroke Rehabilitation, Vol. 27, No. 6, pp. 442–452. DOI: 10.1080/10749357.2020.1716531.
9. **Kessels, R. P., de Haan, E. H., Kappelle, L. J., Postma, A. (2001).** Varieties of human spatial memory: a meta-analysis on the effects of hippocampal lesions. Brain Research Reviews, Vol. 35, No. 3, pp. 295–303. DOI: 10.1016/S0165-0173(01)00058-3.
10. **Merriman, N. A., Roudaia, E., Ondřej, J., Romagnoli, M., Orvieto, I., O'Sullivan, C., Newell, F. N. (2022).** "CityQuest," a custom-designed serious game, enhances spatial memory performance in older adults. Frontiers in Aging Neuroscience, Vol. 14. DOI: 10.3389/fnagi.2022.806418.
11. **Gardony, A., Brunyé, T. T., Mahoney, C. R., Taylor, H. A. (2011).** Affective states influence spatial cue utilization during navigation. Presence: Teleoperators and Virtual Environments, Vol. 20, No. 3, pp. 223–240. DOI: 10.1162/PRES_a_00046.
12. **Moffat, S. D., Zonderman, A. B., Resnick, S. M. (2001).** Age differences in spatial memory in a virtual environment navigation task. Neurobiology of Aging, Vol. 22, No. 5, pp. 787–796. DOI: 10.1016/S0197-4580(01)00251-2.
13. **Organización Mundial de la Salud, Demencia (2019).** Available: http://www.who.int/mediacentre/factsheets/fs362/es/.
14. **Fajnerová, I., Rodriguez, M., Levčík, D., Konrádová, L., Mikoláš, P., Brom, C., Horáček, J. (2014).** A virtual reality task based on animal research–spatial learning and memory in patients after the first episode of schizophrenia. Frontiers in Behavioral Neuroscience, Vol. 8, pp. 157. DOI: 10.3389/fnbeh.2014.00157.
15. **Morris, R. G. (2008).** Morris water maze. Scholarpedia, Vol. 3, No. 8, pp. 6315.
16. **Petridis, P., Dunwell, I., Panzoli, D., Arnab, S., Protopsaltis, A., Hendrix, M., de Freitas, S. (2012).** Game engines selection framework for high-fidelity serious applications. International Journal of Interactive Worlds. Unity Technologies, DOI: 10.5171/2012.418638.
17. **Morris, R. (1984).** Developments of a water-maze procedure for studying spatial learning in the rat. Journal of neuroscience methods, Vol. 11, No. 1, pp. 47–60. DOI: 10.1016/0165-0270(84)90007-4.
18. **Sandstrom, N. J., Kaufman, J., Huettel, S. A. (1998).** Males and females use different distal cues in a virtual environment navigation task. Cognitive brain research, Vol. 6, No. 4, pp. 351–360. DOI: 10.1016/S0926-6410(98)00002-0.
19. **De Castell, S., Larios, H., Jenson, J. (2019).** Gender, videogames and navigation in virtual space. Acta psychologica, Vol. 199. DOI: 10.1016/j.actpsy.2019.102895.
20. **Alvarado, A., Vila, J., Strempler-Rubio, E., López-Romero, L. J. (2011).** Spatial learning and spontaneous recovery in humans. Revista mexicana de análisis de la conducta, Vol. 37, No. 2, pp. 139–153. DOI: 10.5514/rmac.v37.i2.26144.

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