A Preliminary Development of the Morris Maze Procedure in Virtual Reality

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Keywords: Virtual Reality, Human-centered Computing, Psychology and Graphic Input Devices.

Abstract: The Morris Water Maze (MWM) has become one of the most widely used laboratory tools in behavioural neuroscience. It has been used in some of the most sophisticated experiments in the study of spatial learning and memory with animals. However, human-based studies have been very limited due to the use of unrealistic scenarios, usually presented on a computer screen where participants' attention is poorly controlled. Recent advances in virtual reality (VR) enable the generation of 3D environments with a high level of realism and user's immersion. The user's attention plays a key role in spatial learning. Current VR systems integrate eye-tracking devices to measure the user's attention over virtual entities. In this paper, we present an easy-to-use game-based simulator of the MWM, using eye-tracking VR technology to extract information about the user's attention. This research still in progress has achieved important hints according to the design of the virtual scenario, user interaction and experimentation. The study conducted in this paper validates the technology as a novel way to perform MWM focused on spatial learning and memory with human participants.

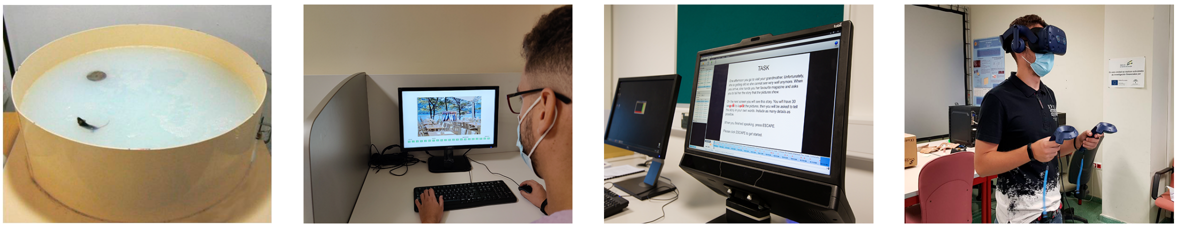
1 INTRODUCTION

The Morris Water Maze (MWM) was defined 40 years ago as a procedure to investigate spatial learning and memory in laboratory rats. It has become one of the most widely used laboratory tools in behavioural neuroscience. This procedure consists of setting a large circular pool filled with opaque water in which a small platform is hidden. In a standard experiment, during the training phase animals learn that different fixed landmarks lead to the position of the hidden platform. Despite being a relatively basic procedure, it has been used in some of the most sophisticated experiments related to neurobiology and neuropharmacology (D'Hooge and De Deyn, 2001). Regarding spatial learning, monitoring attention is crucial. Focusing on monitoring the human's attention, there are multiple devices based on eye-tracking, which are able to record the user's gaze and detect those objects or areas where the human pays more attention (Falck-Ytter et al., 2013) (Marcos and González-Caro, 2010). However, previous studies are usually carried out in non-realistic scenarios using computer screens as context for user interaction. The arrival of virtual reality (VR) allows us to design and generate realistic virtual environments, in which humans live immersive experiences. Moreover, the subsequent incorporation of eye-tracking into VR systems enables monitoring the user's attention with a high spatial resolution. Accordingly, this technology opens new opportunities to assess the human's attention based on already validated procedures within the MWM. Thus, we aim to expand our knowledge about spatial cognition in humans, considering the role of attention in spatial learning.

Figure 1 summarizes some tasks proposed for the study of learning and spatial cognition. In this paper, first steps are presented for the simulation of MWM on VR focused on spatial learning and memory with humans. We propose an easy-to-use framework that enables the creation of multiple spatial learning and memory tasks focused on the user behaviour assessment considering eye-tracking data in VR.

The rest of the manuscript is organized as follows: Section 2 describes the related work, Section 3 is the core of the study, where the experiment design is explained and all the material used is presented, Section 4 shows and discusses the results. Finally, Section 5 concludes the paper and introduces future works.

Moreno, J., Jurado, J., Callejas-Aguilera, J. and Jiménez-Pérez, J.
A Preliminary Development of the Morris Maze Procedure in Virtual Reality.
DOI: 10.5220/0010897500003124
In *Proceedings of the 17th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2022) - Volume 1: GRAPP*, pages 260-267
ISBN: 978-989-758-555-5; ISSN: 2184-4321



a b c d

Figure 1: The progress of spatial cognition and learning studies over time. (a) MWM with rats (SCAC-IRIB, 2020) (b) screen-based human experiments (c) eye-tracking experiments (University, 2014) and (d) our approach.

2 RELATED WORK

The Morris water maze (Morris, 1984) is often considered the "gold standard" test to assess animal learning and spatial memory in a much more accessible and controlled way (Thornberry et al., 2021).

The MWM generally consists of a large circular pool of water maintained at room temperature (or slightly above) with a fixed platform hidden just below the surface of the water. Within this pool, trials are carried out on rats. These trials consist of the execution of a given task by a rat during a fixed time. In each trial, rats are introduced into the pool from a different position (North, East, South, West) and tested individually. The time elapsed and/or the distance traversed to reach the hidden platform is recorded. Distinctive landmarks (geometric images or objects such as circles, squares, triangles, etc.) are often placed on the surroundings. Rats can use these visual cues to guide their navigation. Trial by trial, rats progressively become more efficient at locating the platform. Thus escaping the water by learning the location of the platform relative to the distal visual cues. The MWM provides a highly controlled environment for landmark manipulation, behavioural observation, and lesion studies.

The theoretical development in spatial cognition based on the results obtained with animals in MWM has motivated the interest in establishing similar tasks with which to replicate these results in humans. In addition, these results encourage the evaluation of the adequacy of the theoretical developments initiated with animals, and to advance in the knowledge of spatial cognition. Several procedures have been devised for the study of spatial cognition in humans. One of the most relevant has been the use of virtual reality technology for the implementation of spatial learning tasks (Commins et al., 2020) (Machado et al., 2019). The immediate antecedent of these procedures is found in the use of tasks in which participants had to learn about spatial information presented through a computer screen (Astur et al., 2004) (Livingstone-Lee et al., 2011) (Newhouse et al., 2007) (Newman et al., 2007) (Piper et al., 2010) (Spiers and Maguire, 2008). These tasks favour the rapid completion of spatial cognition studies with a high degree of experimental control. Nevertheless, their results have low external validity since the spatial experience recreated in these tasks differs significantly from actual experience in the natural environment.

Recent advances in virtual reality technology have favoured running tasks such as the evaluation of navigation systems (Roth et al., 2020) (Sitzmann et al., 2018) and the study of spatial memory (Antonova et al., 2011) (Astur et al., 1998). Moreover, other studies have been proposed in order to assess how auditory stimuli can affect the user's visual performance (Malpica et al., 2020). These results validate virtual reality technology concerning traditional laboratory experimentation. According to the MWM procedure, there is not any VR framework with eye-tracking integration as a common standard to replicate and customize the target tasks over different laboratories. Consequently, the comparison between different laboratory results is challenging.

The subsequent incorporation of eye-tracking into VR systems enables monitoring the user's attention with a high spatial resolution. Even though some researchers have used eye-tracking for spatial conditioning and learning, these studies do not integrate this technology in VR (Kiefer et al., 2017). In some approaches, eye movements and physiological measures of memory (pupillometry) are analysed in order to compare visual exploration of spatial orientation. However, this experimentation is limited due to non-immersive tasks just using the computer screen (Mueller et al., 2008).

Thus, the integration of eye-tracking and VR may leverage the knowledge in spatial cognition experiments. In this work, we present the first steps for the development of a game-based simulator in order to study spatial cognition according to the MWM procedure. The main contribution of our proposal is the fusion of both virtual reality and eye-tracking technologies to monitor user behaviour during the experiment. Moreover, the proposed framework is designed to be replicated under specific constraints in order to achieve comparable results between different scenarios. Our solution integrates multiple records and treatments such as time elapsed and/or the distance traversed in the scenario to reach the experiment goal.

3 METHODOLOGY

In this work, a game-based simulator of the MWM procedure is presented. This novel approach aims at providing a new framework to set up experiments in the case of human beings by monitoring both the user's position and gaze in virtual reality. As a contribution of this research, we enable the acquisition of eye-tracking data, which are crucial to analyze the user's attention and the impact of surrounding virtual elements that help to achieve the goal.

To ensure a correct adaptation of the MWM procedure to virtual reality, for the study of spatial cognition and memory, a virtual simulator has been proposed. This simulator includes a realistic scenario and software modules to define the cues and goals of the experiments as well as to capture the time elapsed, the distance traversed or the attention path among others.

The proposed methodology is depicted in Figure 2. Firstly, the MWM logic has to be implemented taking advantage of virtual reality. The adaptation of the original procedure is based on searching for a hidden treasure located in a diaphanous area that simulates the well-known pool of the MWM procedure. To this end, the user can move around and excavate over the area by intuitive gestures using a pick. This area is formed by 12 x 12 digging cells where the treasure is buried (see Figure 3). Secondly, the virtual scenario is modelled. A dense forest is created in which the mentioned area is located. Moreover, target surrounding cues are placed in order to help the user toward the treasure position. This environment ensures immersive experiences enabling users to behave naturally. Thirdly, the MWM procedure must be adapted to be agile enough so multiple designs can be implemented. This allows the realization of different experiments in spatial cognition, memory, learning and conditioning. An important step for the validation of our procedure consists of the replication of basic phenomena in spatial learning such as acquisition and interference. Taking this into account, we have designed an experiment consisting of two learning phases. First, an acquisition phase and then, an interference phase. For both phases, participants aim to look for the treasure whose position is always correlated to two surrounding virtual objects, notated as target cues. In the first phase (acquisition), these entities are located close to the treasure. In the second phase (interference), the treasure position is modified concerning the target cues, being now far away from them, as shown in Figure 4. Thus, a spatial learning function guided by target cues is expected during the acquisition phase, and this one should be disrupted during the interference phase. A spatial learning is expected during the acquisition phase as the time the user spends close to the target cues increases over trials. This learning is also inferred by the number of excavations that take place in the same area. During the interference phase, in which the treasure is located farther away from the target cues, a decrease in behaviour (permanence and digging) in the previous region should be observed. In contrast, an increase of this behaviour should be noticed in the new area in which the treasure is now located. Fourthly, the experiment is conducted with a group of participants and all the relevant information for the study is collected. We recorded the user position, movements, excavations, eye-tracking fixation and transition between entities (related to the attention of each environment object). Heat maps are generated in order to analyze the user's attention and its impact on the user's behaviour. According to the number of excavations, the user path and gaze data, a statistical analysis is carried out. This stage is still in progress. Currently, we are testing the experiment with 32 participants. For the time being, only preliminary results have been obtained corresponding to six users. Finally, the last stage consists of validating the whole process once the data is analyzed.

3.1 Participants

Although the experimentation phase is still in progress, in this study we have collected results from six students aged between 18 and 23 years old of the University of Jaén. The experimental series were approved by the ethics committee of the University of Jaén, protocol number CEIH 250914-2.

3.2 Apparatus and Stimuli

To carry out this study, HTC VIVE Pro Eye hardware (HTC, 2021) and Unity game engine software (Unity, 2021) were used. The study was conducted using a NVIDIA Geforce 1060 3Gb, a recommended GPU by HTC for VR. Stable 90 fps were achieved to avoid sickness from the participants (Hagita et al., 2019).

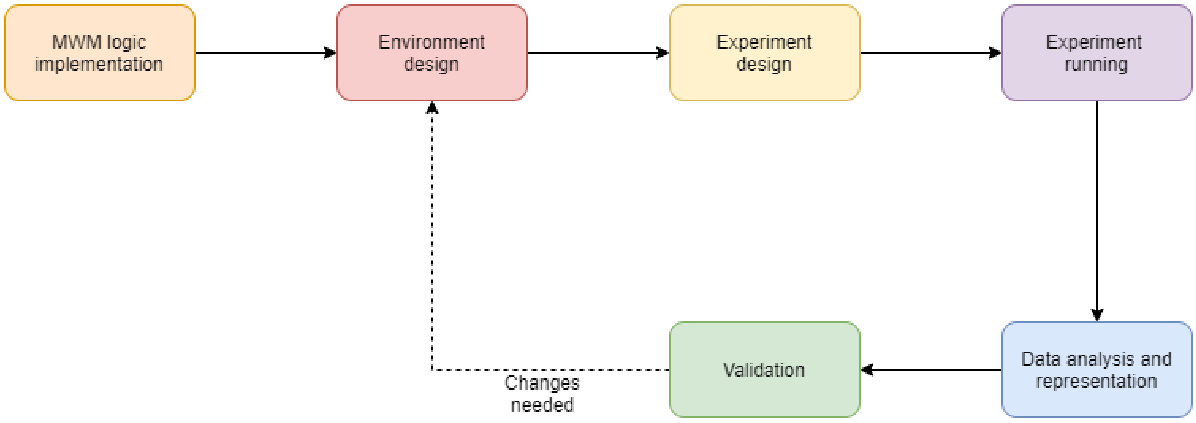


Figure 2: Methodology followed for the adaptation of the MWM procedure to VR and the replication of a spatial cognition experiment.

Figure 3: 12x12 grid located in the diaphanous area where the user is able to dig. Treasure is buried in one grid.

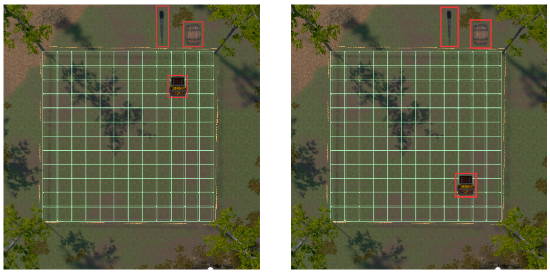


Figure 4: The torch and the barrel represent random target cues. Both, left and right images represent the design of the acquisition and extinction phase respectively.

The final environment consisted of a realistic forest that served as a starting point for our study. It was based on a Unity asset called "Forest Environment - Dynamic Nature" (NatureManufacture, 2021).

Once a realistic environment was selected, the user had the possibility to move around, observe its entities and interact. It ensures a feeling of total immersion and helps users to behave in a natural way which facilitates getting reliable data. The proposed movement within the VR environment is based on the use of teleports. The SteamVR SDK (Valve, 2021) provides teleportation based on zones, distance constraints and user feedback.

For the adaptation of the MWM procedure to VR, some changes are proposed: instead of using a pool as a search space, a diaphanous area delimited by ropes is modelled. A treasure that is buried somewhere in the search area has been proposed as a substitute for the platform that had to be searched in the pool. Objects (landmarks) that help to identify the platform in MWM were replaced by environmental objects (cues) in our adaptation.

As cues, eight items were used. Three of them were irrelevant fixed cues (well, menhir, cabin) that do not indicate the position of the treasure and always remain in the same position. The other five cues were randomly located. Two of them were random target cues (torch, barrel), which indicates the position of the treasure by always maintaining the same relation to it. The other three are random irrelevant cues (skull, little stone, buckets) that do not indicate the position of the treasure.

As a search action, in the Morris maze task, the rat had to swim to find a platform and be in a safe place. In this case, the action consists of digging and moving around the search area until the user finds the treasure for which he/she will be rewarded.

3.3 Procedure

First, participants were asked to read and sign an informed consent before starting the task. Afterwards, once the headset was fitted, the task began.

At the beginning of the experiment, a cover story was told to participants to better acclimate them into the environment. They were told that a friend had taken them to a forest near his home. An ancient civilization lived in that forest and it was attacked by vandals. Before fleeing, they buried their most valuable belongings somewhere in the forest. Their friend had a defined area where he believed they were located. The users' task consisted of finding the treasure and receiving a reward accordingly. In addition, the resources are limited as each dig consumes some coins. If the participants run out of coins, they will not be able to dig until their friend lends them a few.

Just after the cover story, a tutorial began and users were introduced into the environment. The objective was to get the user used to the movement and the environment. After a while, their friend found a treasure and they are moved to its position. At this point, the importance of surrounding elements to achieve the task goal is highlighted.

As mentioned above, the goal of this experiment is the replication of basic phenomena in spatial learning such as acquisition and interference. For this purpose, two phases were created: an acquisition phase and an interference phase. In the acquisition phase, the treasure was hidden close and with the same distance related to the random target cues. In the interference phase treasure was far away from the random target cues (see Figure 4). Each phase consists of 8 training trials. In these trials both treasure and cues were available. Participants were able to dig in the search area and move through the environment. They were introduced into the search area, randomizing their starting position among the North, South, East and West coordinates defined on each side of the search area. The selection of the starting coordinate was done by sampling without replacement to ensure that the user does not repeat a position until he/she has passed through all of them. The search area had a treasure hidden in a different position from trial to trial to avoid that the user could identify the treasure position by using elements of the environment instead of being guided by random target cues. The maximum duration of each training trial was 60 seconds. When the user reached the treasure, he/she stayed at the position for 10 seconds. This delay is done to facilitate the inspection of the entities concerning the position of the treasure. Similarly, if participants did not find the treasure after 60 sec, they were gently pushed to the treasure, where they also remained for 10 additional seconds. Then, a new trial began.

For data analysis, a probe trial is introduced after 4 training trials. Probe trials are identical to training trials with the difference that there is no treasure. Users remain for 60 seconds and then they are advised that this trial has no treasure. This is done to prevent the probe trials from becoming interference trials, i.e., to prevent the participants from thinking that the target cues were no longer good predictors of treasure location. The probe trials are the most relevant since they allow us to observe how the participants distribute their behaviour among the different quadrants during a fixed time of 60 sec.

3.4 Data Analysis and Dependent Variables

Figure 5: Quadrants defined for analysis. They persist between phases. In this trial from the acquisition phase, the green quadrant is defined as the target quadrant as it corresponds to the quadrant where the target keys are located.

For further analysis of the user's performance, 4 equal quadrants are defined (see Figure 5). These quadrants are afterwards delimited zones (not perceptible by the user during the experiment) within the search area. It allows the user's behaviour and learning to be analyzed. In addition, it enables exporting relevant information on the study variables (both, spent time and number of excavations by quadrant). For subsequent analysis, an objective quadrant is defined on which the statistical study of the values will be carried out. This target quadrant corresponds to the quadrant where the target keys are located (green quadrant in Figure 5). Target quadrant position changes from trial

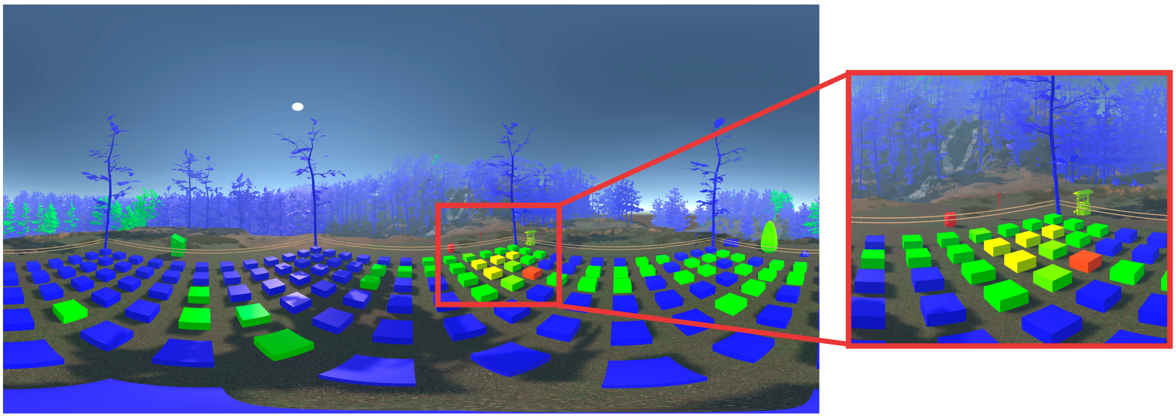


Figure 6: Heat map extracted from the execution of a training trial in the acquisition phase. Grids that appear on the ground represent the different areas where the user could dig. It can be observed how the random target cues (barrel and torch) received the most attention, as well as the digging grids closest to them.

to trial based on the target keys position. The logic of the data analysis is simple: if the task leads to participants learning that the target cues point to the location of the treasure, then as training progresses participants will stay longer, and perform a greater number of digs, in the quadrant where the treasure is hidden. For data analysis, the probe trials should confirm the acquisition and interference that appear during the training trials.

In addition, the eye-tracking system integrated into the VR technology uses a series of algorithms to determine the position at which the user is looking in the virtual world by detecting pupils' position and gaze direction. Using the Unity SDK, objects placed in gaze direction are collided by a ray. It can be obtained all the desired information about the collided objects such as its name, its type (a cue, a digging area, a tree), the position from which it has been observed, time at which the user started to observe the object, number of looks and duration of the gaze fixation, etc. All this information is crucial to evaluate the role of attention in spatial learning.

For the information obtained from eye-tracking, we propose the generation of 360º heat maps to represent the users' attention to different entities in the environment. These heat maps help to validate user's learning through all the trials. In this way, after an execution, a map can be generated where each object takes a colour depending on the total time that the user has been observing it. The continuous range of colours used goes from blue to red (following the colour spectrum), representing lack of attention and maximum time looking at a given entity, respectively. Heat maps are generated for each trial and each user. As an example, Figure 6 shows the heat map from the execution of a training trial by a participant. As can be seen, the random target cues received the most attention from the user as well as the digging area around them. This may confirm that the user has learned which are the cues that indicate the treasure position and the relation between them.

4 PRELIMINARY RESULTS

Time spent in the target quadrant. Figure 7 presents the mean time spent in the target quadrant during the acquisition phase (left side) and the interference phase (right side). In addition to the probe trials, the first training trial during the acquisition phase and the first two training trials of the interference phase have been represented. It is not foreseeable that during these trials the participants would find the treasure, thus maintaining the same characteristics as the probe trials (only one of the six participants found the treasure in these three training trials). As can be expected, time spent in the target quadrant was increasing as the acquisition trials progressed, suggesting that participants learned that the target cues point to the position of the hidden treasure. Moreover, in the second interference trial, a greater permanence is observed, something known in the literature as interference burst (a transient increase in response rate over those observed in baseline during the period immediately following discontinuation of reinforcement of a response (Lattal et al., 2020) (Skinner, 2019)). Finally, a decrease in the time participants spent in the target quadrant can be observed as interference trials followed one after the other. This suggests that the extinguishing treatment was effective. These initial impressions were confirmed by the planned statistical analyses. Comparison of the time spent in the target quadrant between the first training trial in the acquisition phase (when participants do not yet know which

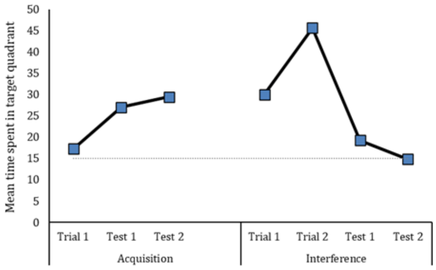


Figure 7: Mean time spent in the target quadrant in the first training trial and the two test trials during the acquisition phase (left side) and the two first training trials and the two test trials during interference phase (right side). The horizontal line at second 15 indicates the mean time expected if the user moves randomly.

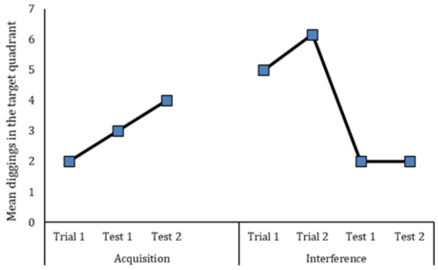


Figure 8: Mean diggings in the target quadrant in the first training trial and the two test trials during the acquisition phase (left side) and the two first training trials and the two test trials during interference phase (right side).

cues may be relevant for treasure location) and the second training trial in the interference phase (when the behavioural expression is maximal as a function of prior learning during the acquisition phase) was statistically significant, $t(5) = 3.67$, $p = 0.01$. The comparison between the second training trial and the last probe trial (when interference should be higher) during the interference phase was statistically significant too, $t(5) = 3.35$, $p = 0.02$. These results show that participants learned to relate the target cues to the treasure location during the acquisition phase and then, that this relationship was disrupted during the second training phase.

Diggings in the target quadrant. Figure 8 presents the mean diggings in the target quadrant in the same training and probe trials as in the previous dependent variable. As can be seen, the number of excavations increased until it reached its maximum value in the second training trial during the interference phase. Thereafter, the number of excavations decreased until reaching its lowest level at the end of the interference phase. These impressions were confirmed by the planned statistical analyses. Comparison of the diggings in the target quadrant between the first training trial in the acquisition phase and the second training trial in the interference phase was statistically significant, $t(5) = 3.20$, $p = 0.02$. Comparison between the second training trial and the last probe trial (when interference should be higher) during the interference phase was statistically significant too, $t(5) = 2.88$, $p = 0.03$.

5 CONCLUSIONS AND FUTURE WORK

The present study attempted to validate a novel way to perform MWM focused on spatial learning and memory with human participants using an eye-tracking VR system. For this purpose, a simple learning acquisition and subsequent interference experiment was designed. The results obtained validate the task and the procedure from a behavioural perspective, showing the tool potential for the joint research of behavioural and attentional processes. However, the validity of the task relies on the confirmation of the results found from statistical analyses guided by theory and a posteriori planned contrast. Although this methodology may be adequate in the replication of a study, it is not sufficient in studies that seek to further advance knowledge of the problem they are dealing with. The lack of results in this study with the a priori analysis strategy may be due to different factors, although three are worth highlighting: First, the number of participants, only 6, which negatively affects statistical power. So, increasing the number of participants could help address the lack of statistical power. On the other hand, the number of irrelevant cues may have hindered the learning of the target cues. Therefore, increasing the number of training trials or decreasing the number of irrelevant cues should enhance the learning function during the acquisition phase. Finally, increasing the duration of training trials should facilitate learning acquisition. Future work in our laboratory will aim at finding parameters that favour task sensitivity for the study of spatial learning and memory. These will also attempt to relate behavioural responses (i.e., displacements and digging) to measures of attention obtained from the recording of participants' eye-tracking during their performance. This may represent an important advance in the understanding of the basic processes governing spatial learning and memory. In addition, we want to exploit the eye-tracking technology, not only through heat maps but also by obtaining the eye transitions of the user on the different entities in the environment. Eye transitions will allow us to know the order in which users were paying attention to different objects and how this could influence their actions.

ACKNOWLEDGEMENTS

Research was supported by *Grant PGC2018-097769-B-C22* from the Spanish Ministry of Science and Innovation and by the Ministerio de Economía y Competitividad and the European Union (via ERDF funds) through the research project (TIN2017-84968-R).

REFERENCES

Antonova, E., Parslow, D., Brammer, M., Simmons, A., Williams, S., Dawson, G. R., and Morris, R. (2011). Scopolamine disrupts hippocampal activity during allocentric spatial memory in humans: an fMRI study using a virtual reality analogue of the morris water maze. *Journal of Psychopharmacology*, 25(9):1256–1265.

Astur, R. S., Ortiz, M. L., and Sutherland, R. J. (1998). A characterization of performance by men and women in a virtual morris water task:: A large and reliable sex difference. *Behavioural Brain Research*, 93(1):185–190.

Astur, R. S., Tropp, J., Sava, S., Constable, R. T., and Markus, E. J. (2004). Sex differences and correlations in a virtual morris water task, a virtual radial arm maze, and mental rotation. *Behavioural Brain Research*, 151(1):103–115.

Commins, S., Duffin, J., Chaves, K., Leahy, D., Corcoran, K., Caffrey, M., Keenan, L., Finan, D., and Thornberry, C. (2020). NavWell: A simplified virtual-reality platform for spatial navigation and memory experiments. *Behavior Research Methods*, 52(3):1189–1207.

D'Hooge, R. and De Deyn, P. P. (2001). Applications of the morris water maze in the study of learning and memory. *Brain Research Reviews*, 36(1):60–90.

Falck-Ytter, T., Bölte, S., and Gredebäck, G. (2013). Eye tracking in early autism research. *Journal of Neurodevelopmental Disorders*, 5(1):28.

Hagita, K., Matsumoto, S., and Ota, K. (2019). Study of commodity VR for computational material sciences. 4(2):3990–3999.

HTC (2021). Htc vive pro eye overview. Accessed on 2021-10-15.

Kiefer, P., Giannopoulos, I., Raubal, M., and Duchowski, A. (2017). Eye tracking for spatial research: Cognition, computation, challenges. *Spatial Cognition & Computation*, 17(1):1–19.

Lattal, K. A., Kuroda, T., and Cook, J. E. (2020). Early extinction effects following intermittent reinforcement: Little evidence of extinction bursts. *Journal of the Experimental Analysis of Behavior*, 114(1).

Livingstone-Lee, S. A., Murchison, S., Zeman, P. M., Gandhi, M., van Gerven, D., Stewart, L., Livingston, N. J., and Skelton, R. W. (2011). Simple gaze analysis and special design of a virtual morris water maze provides a new method for differentiating egocentric and allocentric navigational strategy choice. *Behavioural Brain Research*, 225(1):117–125.

Machado, M. L., Lefèvre, N., Philoxene, B., Le Gall, A., Madeleine, S., Fleury, P., Smith, P. F., and Besnard, S. (2019). New software dedicated to virtual mazes for human cognitive investigations. *Journal of Neuroscience Methods*, 327:108388.

Malpica, S., Serrano, A., Gutierrez, D., and Masia, B. (2020). Auditory stimuli degrade visual performance in virtual reality. *Scientific Reports*, 10(1):12363.

Marcos, M.-C. and González-Caro, C. (2010). Comportamiento de los usuarios en la página de resultados de los buscadores. un estudio basado en eye tracking.

Morris, R. (1984). Developments of a water-maze procedure for studying spatial learning in the rat. *Journal of Neuroscience Methods*, 11(1):47–60.

Mueller, S. C., Jackson, C. P. T., and Skelton, R. W. (2008). Sex differences in a virtual water maze: An eye tracking and pupillometry study. *Behavioural Brain Research*, 193(2):209–215.

NatureManufacture (2021). Forest environment - dynamic nature. Accessed on 2021-10-15.

Newhouse, P., Newhouse, C., and Astur, R. S. (2007). Sex differences in visual-spatial learning using a virtual water maze in pre-pubertal children. *Behavioural Brain Research*, 183(1):1–7.

Newman, E. L., Caplan, J. B., Kirschen, M. P., Korolev, I. O., Sekuler, R., and Kahana, M. J. (2007). Learning your way around town: How virtual taxicab drivers learn to use both layout and landmark information. *Cognition*, 104(2):231–253.

Piper, B. J., Acevedo, S. F., Craytor, M. J., Murray, P. W., and Raber, J. (2010). The use and validation of the spatial navigation memory island test in primary school children. *Behavioural Brain Research*, 210(2):257–262.

Roth, D., Purps, C. F., and Neumann, W.-J. (2020). A virtual morris water maze to study neurodegenarative disorders. In *2020 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, pages 141–146. IEEE.

SCAC-IRIB (2020). Mwm with rats image reference. Accessed on 2021-11-02.

Sitzmann, V., Serrano, A., Pavel, A., Agrawala, M., Gutierrez, D., Masia, B., and Wetzstein, G. (2018). Saliency in VR: How do people explore virtual environments? *IEEE Transactions on Visualization and Computer Graphics*, 24(4):1633–1642.

Skinner, B. (2019). The behavior of organisms: An experimental analysis.

Spiers, H. J. and Maguire, E. A. (2008). The dynamic nature of cognition during wayfinding. *Journal of Environmental Psychology*, 28(3):232–249.

Thornberry, C., Cimadevilla, J. M., and Commins, S. (2021). Virtual morris water maze: opportunities and challenges. *Reviews in the Neurosciences*.

Unity (2021). Unity game engine. Accessed on 2021-10-15.

University, L. (2014). Eye tracking image reference. Accessed on 2021-11-02.

Valve (2021). Steam vr sdk for unity. Accessed on 2021-10-15.