Spatial Mnemonics using Virtual Reality

Eric Krokos
University of Maryland
College Park
USA
EKrokos@umiacs.umd.edu

Catherine Plaisant
University of Maryland
College Park
USA
Plaisant@cs.umd.edu

Amitabh Varshney
University of Maryland
College Park
USA
Varshney@umiacs.umd.edu

ABSTRACT
Virtual reality displays, such as head-mounted displays (HMD) can provide superior spatial awareness by leveraging the vestibular and proprioceptive senses. Since the classical times, people have used memory palaces as a spatial mnemonic to help remember information by organizing it spatially in an environment and associating it with salient features in that environment. This paper reports a user study exploring whether using virtual memory palaces with a head mounted display (HMD) improves recall over using a traditional desktop display. Forty participants were asked to recall faces seen on both types. A statistically significant improvement of 8.8% in recall accuracy was found for HMD over Desktop. Users reported higher satisfaction as well. This could be a first step in using virtual environments for creating memorable experiences that enhance productivity through better recall of information organized in virtual memory palaces.

CCS Concepts
• **Human-centered computing →Virtual reality;** *Graphical user interfaces; HCI theory, concepts and models; Interaction design theory, concepts and paradigms; Visualization theory, concepts and paradigms;*

Keywords
Immersion; Experimental Methods; HMD; Psychology; User Study; Presence

1. INTRODUCTION
Since the classical times people have used memory palaces (method of loci), taking advantage of the brain's ability to spatially organize thoughts and concepts. In a memory palace, one mentally navigates an imagined space to recall information [1]. Throughout history, humans have always been fascinated with how technology can help us remember information. From cave painting, clay tablets, and papyrus, to modern paper, audio, and video, we have used tools to encode and then recall information. Virtual environments offer a promising next step in the quest to help users store and recall information.

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The results presented here indicate a statistically significant improvement in recall when using virtual memory palaces in immersive, head-tracked HMDs compared to traditional desktops. This work will hopefully encourage designers to consider using memory palaces when developing virtual environments for applications such as entertainment but also data analysis, education or rehabilitation.

2. RELATED WORK
Memory palaces have been used since the classical times to aid recall by using spatial mappings and environmental attributes. Due to space limitations, only a subset of related work is discussed below.

Legge et al. [2] have compared traditional mental memory palaces (method of loci) against virtual memory palaces. In this study, the subjects were divided into three groups. The first group was instructed to use a mental memory palace, the second group a virtual memory palace, and the third (control) group was not informed on the use of any mnemonic device. The subjects in the three groups were given 10 to 11 uncorrelated words and asked to memorize the words with their mnemonic device, if any. The users then had to recall the words serially. The study found that the users who used a virtual memory palace performed better than those using a mental memory palace, and those who were not instructed on a memory strategy did not perform as well as those who were instructed to use the memory strategy. In the virtual memory palaces used in the study, the participants were expected to imagine the words associated with parts of the virtual memory palace, and that they did not actually see the words rendered in that environment. In study presented in this paper, the participants actually see the information to be recalled, i.e. faces, within the virtual memory palace, rather than just mentally imagining the content. In addition, the subjects in the previous study navigated the virtual memory palace on a desktop and did not experience it in an immersive display or HMD.

Pausch et al. [3] studied if immersion in a HMD aids in searching and detection of information. In their study, they created a virtual room with letters distributed on walls, ceiling, and floor. A user was placed in the center of this room and was asked if a set of letters was present or not. The test was conducted using a HMD and a traditional display with a mouse and keyboard. They found that when the search target was present, the HMD and the traditional display had no statistically significant difference in performance. However, when the target was not present, the users were able to confirm that target was missing more quickly in the HMD than the traditional display. In addition, the users that used the HMD first and then moved to a traditional display had better performance than those who used the display first and then the HMD. This suggests a positive transfer effect from HMD to a desktop. The user study presented in this paper was highly influenced by the design of the study done by Pausch et al. [3], but in the study presented in this paper, the users perform recall rather than search.

Wraga et al. [4] compared the effectiveness of vestibular and proprioceptive rotations in assisting recall by having participants recall on which of the four walls was an object located relative to their orientation before and after rotation. Participants were placed in a virtual room with four distinctly colored alcoves on four walls and given time to learn and recognize the alcoves. Participants would rotate, using either the HMD accelerometer or a joystick, to find a certain object on one of the alcoves as described by the tester. Once the user was looking at that object on one of the alcoves, their view would be frozen and the tester would ask the participant to state where a particular (different) alcove was relative to their orientation. The authors found that users in a HMD were better able to keep track of their orientation and the location of objects by rotating their heads using the HMD accelerometer as compared to using a joystick for an equivalent scene rotation. In another experiment, the authors also found that users in a HMD who controlled their bearing in a virtual world by actively rotating in a swivel chair were better able to keep track of an object than those that were being rotated by a tester.

Ragan et al. [5] investigated if the addition of supplemental spatial information affected the performance of learning-based activities within virtual environments. The authors conducted a user study by showing information to participants in either a spatial or non-spatial presentation and compared memory recall scores. In addition, the study compared the effectiveness of background landmarks in spatial memorization. The study showed that the spatial presentation resulted in statistically higher performance. The authors concluded that supplemental spatial information can affect mental strategies and support performance improvements for cognitive processing and learning-based activities.

Perrault et al. [6] leveraged the method of Loci technique and had users memorize commands by linking the commands to physical objects within a real room. They compared their interaction technique to a mid-air swipe menu that relies on directional swiping gestures. The idea was to leverage spatial, object, and semantic memory to help users learn and recall a large number of gestures and commands. They found that users, when using their Physical Loci technique, were able to have nearly perfect command recall compared to the mid-air swipe menu.

Harman et al. [7] investigated the effect of immersion on memory recall by having participants simulate the experience of boarding an airplane in a virtual airport. Those participants who experienced the scenario in a HMD had more accurate recall of the events and processes of their boarding than those who used the desktop. In contrast to the study in this paper, the participants were asked to recall the events outside of the virtual scenario, through a traditional questionnaire.

3. USER STUDY

Previous work has examined the role of spatial organization, immersion, and interaction in assisting recall. This study differs in several ways. First, the focus is on spatial memory, rather than relying on other forms of memory (episodic) or relying only on mental techniques. Second, both the training and testing (recall) phase takes place within the virtual environment. Lastly, the content used in previous studies was either abstract, verbal, textual, visually simplistic, low in diversity, or time-based, while the data in our study, faces, is purely visual with unique and diverse characteristics across samples. The goal of this user study is to examine if a virtual memory palace, experienced immersively in a head-tracked stereoscopic head-mounted display, can assist in recall better than a mouse-based interaction on a traditional, non-immersive, monoscopic desktop display.

Figure 1. The two scenes used in the user study (a) an ornate palace, and (b) a medieval town, as seen from the view of the participants. The recall phase of the study is shown in (c).

3.1 Hypothesis

The hypothesis presented in this paper is that a virtual memory palace experienced in an immersive head-tracked head-mounted display will lead to more accurate recall than on a mouse-controlled desktop display.

3.2 Setup

This study compared two displays: a traditional desktop with a 30" monitor and an Oculus DK2 HMD. The rendering resolution for both the Oculus DK2 and the desktop was set to 1080x1200 with a rendering field of view (FOV) of 100◦ degrees. The task consisted of recalling faces seen in a scene. Using a within-subject design each participant repeated the task twice: once using the desktop and the other using the head mounted device. To reduce learning effects two scenes were used, and two sets of faces. The order of display presentation, scene used, and set of the faces was counterbalanced across participants.

One scene consisted of a palace and the other a medieval town environment, both filled with faces. Given the previous work from [8, 9] showing the effectiveness of users recalling face-name pairs, this study used two sets of faces of people considered to be well known. The faces were placed in both scenes at varying depths away from the camera, with the camera placed in the center of the scenes.

4. PROCEDURE

Forty participants with normal or corrected-to-normal vision were recruited on campus (of which 30 were male and 10 were female). The study session for each participant lasted around 45 minutes. First, participants were given printed pages showing the 42 faces used in the study, with names, and asked to familiarize themselves with who they would later be asked to recall.

Next, the participant would be placed either in front of a desktop monitor with a mouse or inside a head-tracked HMD. The participants were given as much time as they wanted to get comfortable with the desktop and HMD displays, looking around the scene (without numbers or faces). The users rotated the scene on a desktop monitor by panning or moving a traditional mouse and in the HMD they rotated their head and body; no zooming, walking, or moving the camera was permitted.

Once the participants were comfortable with the setup and the controls, a set of 21 faces were added to the 3D scene, distributed around the entire space – a palace and a medieval town, as shown in Figure 1. Each participant was tested in both displays but the order presentation, scene used and set of the faces was counterbalanced across participants. In addition, the ordering of the scenes and faces were changed across participants to cover all possible combinations of exposures. The participants were given five minutes to memorize the faces and their locations within the scene. After the five minute period, the display went blank and the participants were given a two-minute break in which they were asked a series of distracting and non-related questions. This break was added to avoid recall from short-term memory.

After two minutes, the scene would reappear on the display with numbers having replaced the faces, as shown in Figure 1(c). The participants were then asked to recall, in any order, which face had been at each numbered location. During this recall phase, the participants were able to look around and explore the scene just as they did in the training phase, using the mouse on the desktop or rotating their head-tracked HMD. For each numbered location in the scene, the participants verbally recalled the face at that location. The participants had up to five minutes to recall all the names of faces in the scene. Once the participant was confident in all their answers, or the five-minute period had passed, the testing phase ended. After a break, the participants were placed in the other display that they had not previously tested with, using a different scene and a different set of 21 faces. Participants were told that they could use mnemonics to help remember the locations and ordering as long as the participants used the same mnemonic for both scenes. After completing the two tasks participants were given a short survey, and asked to comment on their experience with both displays.

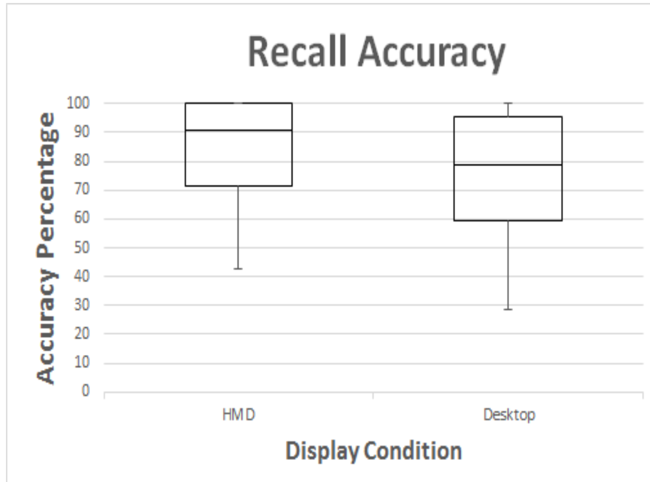

Figure 2. The mean recall accuracy for HMD is 84.05% and for desktop display is 75.24% (a statistically significant 8.8% improvement). The thin bars show the min and max values. The two boxes show the standard deviation around the mean.

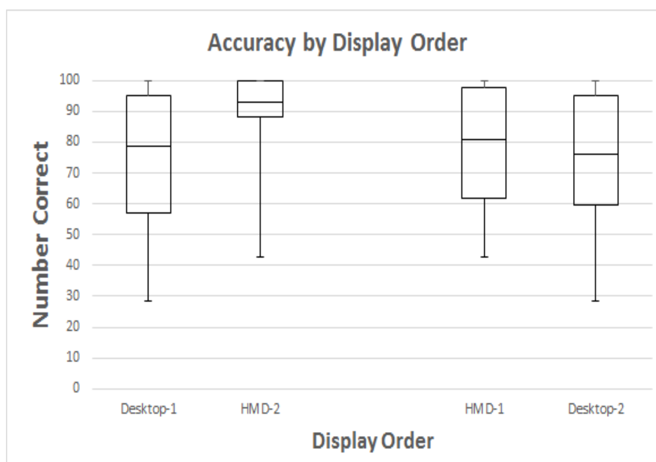

Figure 3. The average performance of participants going from a desktop to a HMD and from a HMD to a desktop, with the standard deviation shown in the two boxes. The error bars show the min and max values.

5. RESULTS AND DISCUSSION

Using ANOVA, it was confirmed that there were no significant effects on recall for scene (palace versus town, $F(1, 79) = 0.27$, $p > 0.05$), set of faces ($F(1, 79) = 0.27$, $p > 0.05$); but there was a significant effect for the display type (HMD versus Desktop) with $F(1, 79) = 4.6$ and $p < 0.05$. It was found that the overall recall performance of participants using a HMD was 8.8% higher compared to a desktop. The mean recall accuracy for HMD at 84.05% and the desktop display at 75.24%. A paired t-test showed that the improvement was statistically significant: $p = 0.0017 < 0.05$. Figure 2 summarizes the results.

This result confirms the hypothesis, i.e. participants using the HMD were more accurately able to recall information than when using a traditional desktop. In the study, the order in which users were exposed to the two displays were counterbalanced. Figure 3 shows the accuracy when using a desktop first then a HMD and using a HMD first and then a desktop.

During the first task there was no significant difference in accuracy between HMD and desktop (average is 78% on the HMD and 75% on the desktop, $p = 0.62 > 0.05$). However, when going to the second display, the performance changed differently depending on the order of presentation. When users went from a desktop to a HMD, their performance generally improved with those who used the HMD second having an average score of 89% and those on the desktop maintained 75%. In contrast, when the users went from a HMD to a desktop, their performance decreased. A possible explanation might be that that those who use the HMD first are able to use the proprioceptive advantages the HMD offers but when they transfer to the desktop, they miss the spatial sense and find it harder to perform the task correctly. When the users start on the desktop, they might be able to memorize the information, but when they transfer to the HMD, they gain an improved proprioceptive sense and benefit from the HMD, and therefore perform better.

Overall, the hypothesis regarding accuracy was confirmed. Preference was in favor of HMD despite users' longer experience with desktop displays. While the performed task may be representative of realistic tasks, a more difficult task could reveal more subtle differences between the displays. Accuracy was high despite the fact that faces require two levels of memorization: the name and the face (in addition to the spatial memorization that also required). Only a few faces corresponded to difficult-to-remember names and users could describe them adequately enough to be recorded as a face correctly remembered. This confirms that face recall is practical for the study of virtual environments.

Lastly, each participant was asked which display he or she preferred in terms of achieving the task of recall. It was explicitly stated that their decision should not be based on the novelty or "coolness" of the display or the experience. All but 2 of the 40 participants stated they preferred the HMD for this task. They further stated that they felt more immersed in the scene when using the HMD. In addition, a majority of the users (~70%) reported that HMD afforded them a superior sense of the spatial awareness which they claimed was important to some of their success.

6. CONCLUSIONS

The results of the study suggest that the use of virtual memory palaces in HMDs improves recall accuracy compared to using a traditional display. Forty participants were recruited to memorize and recall faces on two display modalities for two virtual memory palaces, with two different sets of faces. Between the HMD and Desktop, there was an 8.8% improvement in the average recall accuracy, which was found to be statistically significant. The results of this study increase our understanding of the effective use of immersive virtual environments.

The results of this study provide an alluring glimpse into the possibilities for memory enhanced virtual-environment-based tools and visualizations. Moving forward, the next steps would be to identify which aspects of virtual reality and virtual environments are most effective in supporting superior information recall. These elements could include the layout and design of the virtual environments, the visual saliency and structure of the 3D models used [10], and the type and manifestation of the content to be displayed. Another interesting direction would be the integration of the user into the construction of their own personalized virtual environments, and then evaluate their recall ability using those environments as compared to environments constructed by others. If an active participation in the organization of the virtual space and data proves to make a difference that could further drive the future design of virtual reality based information management and visualization tools. Another future direction could be to explore which elements of virtual environments that are useful for the individual versus those used by larger groups. There is a push to bring education into the virtual space, and as much as individuals and groups use textbooks and videos, it could be possible that these virtual environments could be used for an effective transfer of information between and amongst each other.

7. ACKNOWLEDGMENTS

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AUTHORS' BACKGROUND

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Your Name	Position	Email	Research Field	Personal website
Eric Krokos	Phd Candidate	EKrokos@umiacs.umd.edu	Virtual Reality and Visualization	
Catherine Plaisant	Full Professor	Plaisant@cs.umd.edu	Human-Computer Interaction	http://hcil.umd.edu/catherine-plaisant/
Amitabh Varshney	Full Professor	Varshney@umiacs.umd.edu	Virtual Reality and Visualization	https://www.umiacs.umd.edu/people/varshney