Method of Loci and Memory Recall in Virtual Reality - A User-Generated Exploration

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ABSTRACT

This paper proposes the idea that 3D object creation can work as a potential method to helping users apply the Method of Loci (MoL) in Virtual Reality (VR). In order to explore this alternative, the paper also introduces a prototype application of a content creator tool that can allow users to instantiate objects within a VR environment easily. Through experimentation with participants in a VR environment, key design issues surrounding this prototype have been made apparent, and thus this paper elaborates on how this content creator tool can be improved for future works. This paper also offers suggestions on how to improve the experiment procedure utilized in this paper and describes key aspects about the MoL technique in VR that should not be ignored.

Keywords: Virtual Reality – Memory Recall – Mnemonics - Method of Loci – System Control – 3D Widgets – Interaction Metaphors

Index Terms:

1 INTRODUCTION

The Method of Loci (MoL) is a well-established mnemonic method for memory recall and retention and is widely referenced in the fields of psychology, popular media, and mental health. Mnemonic methods in general usually involve recollection of facts by mapping them with particular objects, also known as "loci" in the literature. When the user wishes to recall certain facts or words, the user simply has to recall the loci in the ordering the user has dedicated to memory.

The mapping process, choice of loci, and method of memory storage have seen variations over time, from a pure one-to-one mapping between fact and object (ex. a numeric pegboard method) to the association of a fact with an icon or behavior related to a location [1]. The Method of Loci is one of these mnemonic methods wherein individuals map facts with icons or behaviors associated with physical locations that the user knows well. For example, if the homeowner wishes to memorize a list of items for a shopping list using the Method of Loci technique, they must map the food items to the locations in some imaginative way such as the splattering of tomatoes on the front door or bread loafs hanging off of his coat hangers. In this regard, it is the pathway the homeowner envisions that allows for the Method of Loci to work effectively. If icons are used concurrently with locations during this mapping process, they are usually imaginative in nature, relying on the user's ability to depict relationships between referrants and icons to facts.

The mnemonic process of memory recall and retention is deeply personal and unique to each individual, and as such it is often difficult to gauge its efficacy from a research perspective. Yet, previous research into this topic has made strides in determining how MoL works and how it can be applied in a variety of situations. One of these situations is Virtual Reality (VR), which has also garnered the attention of researchers due to its effect on human perception and cognition. This paper proposes an alternative take on the implementation of MoL in VR by adding a creative component to the mapping process. In particular, this paper suggests that allowing users to create custom-made 3D objects and place those objects at loci in the virtual environment can be a viable implementation of MoL.

This paper focuses on a dual-pronged approach to determine the validity of this alternative MoL application. Firstly, this paper will explore an experimental methodology that can be used to determine if object creation can be an effective alternative to using simple images in a VR application of the MoL technique. Secondly, this paper will highlight the design aspects and functionality of a content creation tool that can be used to execute this experimental methodology.

2 RELATED WORKS

2.1. The Method of Loci Technique

The Method of Loci is classified as a mnemonic memorization technique and has been popularized under the colloquial term "Mind Palace". The first recollection of MoL comes from Cicero in *De Oratore*, wherein Cicero recounts the story of Simonides and how Simonides was able to recall the identities of those who had been crushed to death from a collapsed roof by associating the bodies with their locations within the collapsed banquet hall [2]. As Cicero recounts:

> "[Simonides] inferred that persons desiring to train this faculty (of memory) must select localities and form mental images of the facts they wish to remember and store those images in the localities, with the result that the arrangement of the localities will preserve the order of the facts, and the images of the facts will designate the facts themselves, and we shall employ the localities and images respectively as a wax writing tablet and the letters written on it." (354-355)

It wouldn't be until 1966 when this definition of MoL is defined under a more contemporary description by Yates [3] (See Appendix). A paraphrase of Yates' original description of the MoL technique is described as:

> "The Method of Loci is a technique where memories are imprinted into a series of places, or 'loci'. In order to form a series of loci in memory, a location needs to be remembered and distinct parts of that location need to be memorized - these act as your 'loci'. Then, images representative of the words that are to be remembered are placed in the imagination at these memorized loci. An example of this is a speaker moving, in their imagination, through his memory building while making his speech, drawing from the memorized loci the images he has placed."

This was later expanded upon by Gordon H. Bower in 1970, who identified different mnemonic memorization techniques and pointed out nuances when it comes to executing these mnemonic techniques [1]. Bower goes into detail on nine of the more salient aspects when it comes to the application of the MoL technique with list items and provides a foundation on

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which the application of MoL should ideally rest on (see Appendix).

Contemporary use cases of the MoL technique are seen in a variety of situations spanning competitive sports to medical therapy. Eight-time World Memory Champion Dominic O'Brien cites this technique when describing his "Memory Town System" [4], and Gary Shang has been cited to have used the MoL to memorize pi to over 65,536 (2^16) digits [5]. MoL has also been shown to help sufferers of depression remember positive, self-affirming memories [6].

2.2. Virtual Method of Loci

The implementation of the MoL technique in a virtual setting has been the focal point of research in several cases, as many have tried to ascertain how much serial recall rates have been affected by the use of virtual environments rather than physical ones in the real world. Legge and co. tested the efficacy of the MoL technique in a comparison between conventional learning techniques, conventional MoL (cMoL) within an environment familiar to the user, and virtual MoL (vMoL) in a desktop-based virtual environment with keyboard and mouse [7]. No significant differences between vMoL and cMoL were observed, implying that MoL with virtual environments can be just as effective as conventional uses of MoL in physical environments.

Later in 2017, Huttner and Robra-Bissantz discussed a direct comparison between vMoL and an HMD-based MoL implementation, with the results indicating that while recall rates were higher between HMD MoL over vMoL, the mean difference was not statistically significant [8]. The paper discusses that presence was a big factor with HMD MoL, with the lack of auditory footsteps being the primary example, and that future works should attempt to find a correlation between immersion rates and accuracy rates.

These findings were replicated in 2019, where Krokos, Plaisant, and Varshney found similar results with their direct comparison between vMoL and HMD MoL [9]. In their findings, recall rates were higher with HMD MoL over vMoL, and error rates were substantially lower for HMD MoL over vMoL. Similarly to Huttner and Robra-Bissantz's paper, this paper discusses how, to users, the increased spatial awareness of the virtual environment with HMD's was paramount to their success, but a reduced sense of immersion in the VR world led to decreased focus on the task at hand. It must be noted that unlike Legge's and Huttner's implementations, Krokos's implementation involves user-generated content in the form of placing images at loci, rather than purely an imaginative mapping of word items to virtual locations. As such, the mechanisms by which users interact with the environment beyond navigation also have a hand in immersing users into the virtual world.

In one unique case, a paper by Vindenes, de Gortari, and Wasson investigated recall rates with HMD MoL, vMoL, and cMoL but found that cMoL outperformed vMoL and HMD MoL [10]. An inquiry into the results implied that participants who exhibited higher spatial learning capability were more likely to successfully employ the MoL technique than those with low spatial learning ability and that the necessity to navigate in 3D within the virtual world put significant stress on users of HMD MoL by adding time within a time-constrained learning period. Similarly to Krokos's implementation, Vindenes' implementation also allowed for user-generated content in the form of images to be placed in the virtual environment, but in this case users were allowed to choose the loci at which they would place their images, whereas all previous papers mentioned do not allow for such freedom. This reveals that any successful implementation of HMD MoL should reduce time dedicated to navigation and that considerations for spatial learning ability is a must when processing user data.

2.3. 3D Interaction Modalities for Content Creation

Amongst existing examples of content creation tools within the realm of VR, most applications consist of a multimodal combination of 2D palettes and 3D interaction mechanisms. Examples such as the Holosketch [11], 3D Palette [12], and more recently Gravity Sketch [13] usually feature a 2D-styled interface wherein different functions are tied to buttons on the 2D interface. While the appearance of menus and buttons in these examples are 3D in nature, their orientation lies on a 2D interaction plane. Conversely, interaction with these 2D menus is based on commonly-used 3D interaction metaphors such as grabbing, pointing, and 3D widgets [14], In order to allow for the precision and accuracy expected of creation tools by users, 3D widgets such as pointers and styluses are typically used for both selection of buttons on the 2D palette and the creation of content via dragging and hovering. The decision to use 2D menus and 3D widgets for selection is tied closely to Fitt's Law, which suggests that interacting with 3D menus by physically touching them with a pointer or 3D widget is more time consuming than using 2D menus due to the travel distance in space between menu items in 3D [19]. Gillan and co. further elaborate that a combination of point-click and point-drag interaction metaphors be used for systems in 3D space in order to reduce interaction time as effectively as possible.

Mechanisms of user interface (UI) design that allow for the creation of 3D objects in VR are also rooted in heuristics associated with system control. According to LaViola [14], various factors must be considered when designing 3D UIs in VR. A general summary of tips and suggestions from LaViola mention to:

1. Avoid disturbing the flow of action of an interaction task
2. Prevent unnecessary focus switching and context switching
3. Design for discoverability
4. Avoid mode errors
5. Use an appropriate spatial reference frame
6. Structure the functions in an application and guide the user
7. Consider using multimodal input
8. 3D is not always the best solution - consider hybrid interfaces

Sutcliffe and Gault [15] (see Appendix) define a list of heuristic evaluations to be considered when evaluating virtual reality applications, which in of itself is based on an earlier heuristic evaluation methodology defined by Nielsen [16]. Following these heuristic evaluations is essential for any VR system, more so for the application of the MoL as previously seen with earlier MoL papers.

3 Implementation

In order to test the efficacy of MoL and offer an experience that improves immersion in VR, a prototype system for content creation has been designed. The prototype system uses a combination of 2D and 3D interaction modalities to provide a user flow that feels comfortable to use. Both the prototype system and the virtual environment are developed with Unity3D and are playable on the Oculus Quest and Rift.

3.1. Interface Design

The interface of this content creation system utilizes a combination of 2D palette menu and a 3D tooltip. This 2D menu is affixed to a virtual controller corresponding to the user’s non-dominant hand, whereas the tooltip is affixed to the virtual controller corresponding to the user’s dominant hand. The 2D menu consists of a palette of prefabricated objects, or “prefabs,” that the user can select by touching the tooltip of their dominant hand to the palette where the prefabricated object is represented. The palette itself allows for several key functions, such as allowing users to cycle through the list of prefabs available to the user and saving the status of the virtual world for later use should the user decide to leave the virtual world.

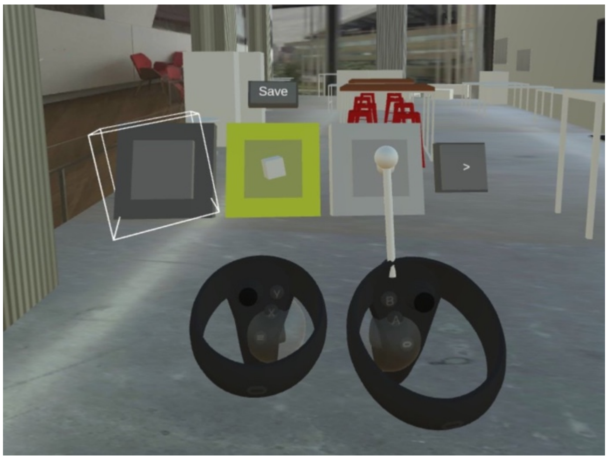

Figure 1: The prefab palette fixated to the left controller, alongside the tooltip on the right controller. Note the coloration of the palette buttons to indicate unclicked, selected, and highlighted status.

The controllers of the Oculus Quest and Rift offer additional buttons and joysticks that are also mapped to other functions of the system. These functions include:

1. Continuous movement through the VR environment.
2. Blink teleportation for users with low tolerance for vection.
3. Rotation of the player body at 22.5-degree intervals
4. Color picker toggle
5. Scaling type toggle between the prefab’s original scale and the scale defined by the difference between the user’s initial tooltip position at the start of the drag and the current position of the tooltip.
6. Deleting objects in the world
7. Cycling through the palette list of prefabs

3.2. Object Instantiation and Manipulation

To instantiate new objects into the world, the user must:

1. Select a prefab from the palette by touching the prefab with the tooltip.
2. Drag the tooltip while holding the index trigger to scale the object prior to placement in the virtual world.

Once objects have been instantiated in the world, the user is allowed to manipulate the position and rotation of the object via a grab metaphor with either controller as well as re-color the object via joystick toggle on the dominant hand’s controller. Objects cannot be rescaled once they are instantiated in the world. Objects can also be deleted or copied, the functions of which are mapped to buttons on the dominant hand’s controller.

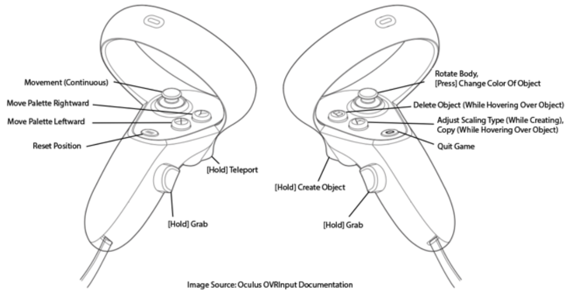

Figure 2: The control scheme of the content creation tool on both controllers of the Oculus Quest.

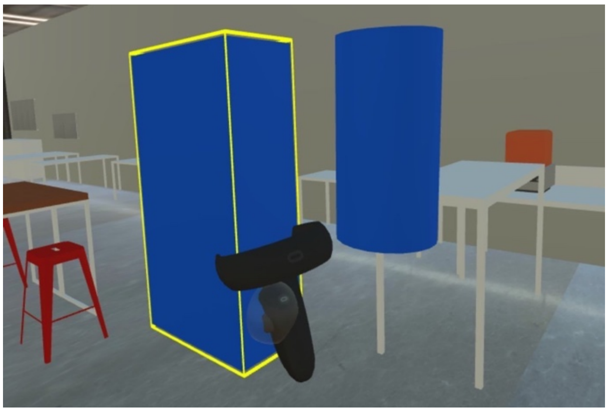

Figure 3: A hover cursor to indicate which object the user is able to grab, re-color, and delete, versus another object that is not hovered over.

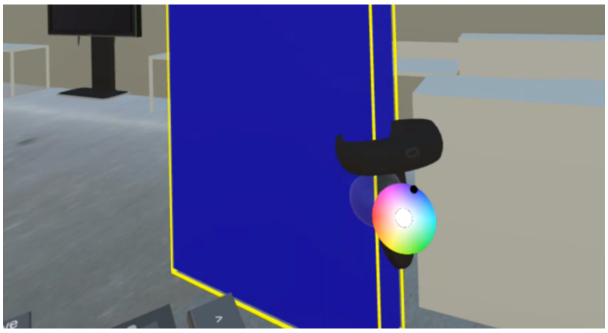

Figure 4: The color picker that appears over colorable objects.

3.3. Locomotion

Locomotion within the virtual environment is divided into two subcategories: positioning and rotation. The player avatar in the virtual environment follows the position of the headset using the headset’s 6-DOF sensors. Therefore, users can adjust their position in the virtual environment either by moving physically in real-world space or by using the joystick on the non-dominant controller for continuous locomotion. Players can also move around the virtual environment via blink teleportation, which reduces motion sickness from vection as well as reduces the time necessary to navigate across the virtual environment, which was a problem in previous studies involving MoL.

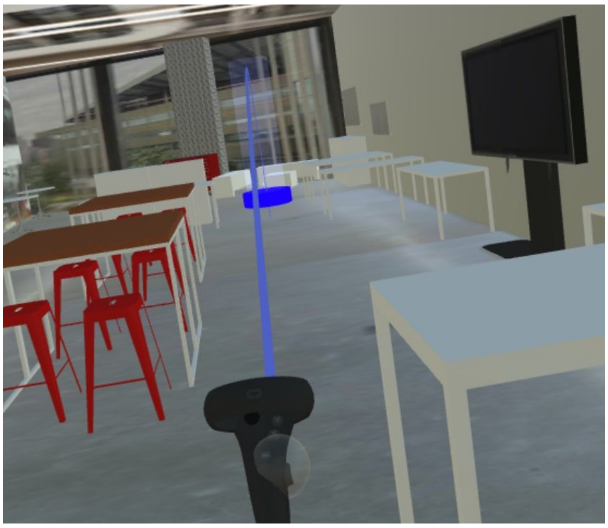

Figure 5: Locomotion via blink teleportation.

Rotation is performed by either rotating the user's physical body and head or by pushing left or right on the dominant controller's joystick. Rotation occurs in snap intervals of 22.5 degrees as a measure to reduce vection caused by continuous rotation of the body.

4 METHOD

The experiment required to investigate the efficacy of a content creation system with MoL in virtual reality is a multi-step user experiment wherein participants have to remember the contents of four word lists using the MoL technique within a virtual environment.

4.1. Technology

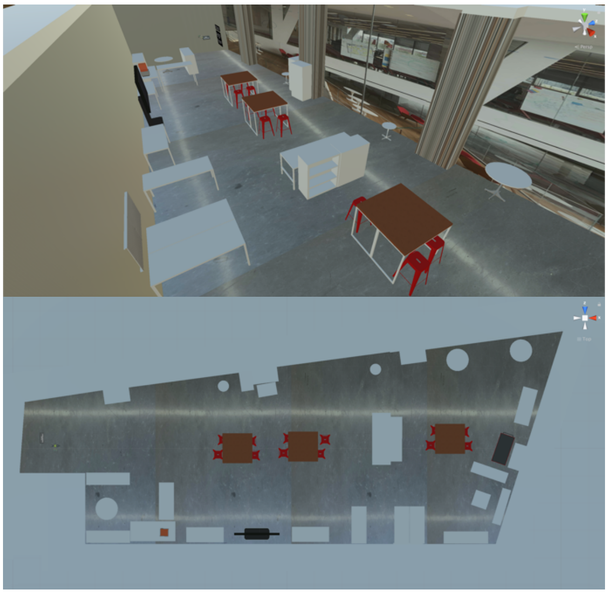

Figure 5: A 3rd-person and bird's eye view of the testing environment.

The virtual environment in question is a 3D rendering of Cornell Tech's MakerLab. The virtual environment is populated with renderings of furniture commonly found in the real-world MakerLab such as chairs and tables, and the virtual environment attempts to replicate lighting conditions typically present in the real-world MakerLab. Participants of this experiment are required to utilize this environment with the MoL technique and are restricted from exiting the virtual environment. Colliders that match the shape and orientation of the walls, floor, and ceiling prohibit the player avatar from moving outside the test area. The virtual environment was built with and edited using Unity3D, and the game environment runs with Unity's proprietary game engine alongside Oculus' OVR Implementations SDK for VR support. Participants are restricted to using an Oculus Quest or Rift for the purposes of this experiment. All participants are given the custom content creation tools, which offers object instantiation grabbing and locomotion functionality.

During the experiment, participants are required to maintain contact with the experimenter by online video and audio telecommunication. This channel allows for the experimenter and participants to engage in guided training of the content creation tool, directed testing sessions with verbal instruction provided from the experimenter, and Q&A about the mechanisms behind the content creation tool. Participants were also required to have access to a web browser as a means to answer online pre-test and post-test questionnaires concerning the virtual experience.

4.2. Participants

Participants for this experiment range from between 24 and 28 years old and consist of two individuals, one male and one female. Participants both personally own or have access to an Oculus Quest or Rift and both have had prior experience working and developing virtual environments in VR. Consequently, both participants are also knowledgeable about Unity3D development. Both participants have prior experience working in the real-world MakerLab, which is preferred as participants do not need extra training time dedicated purely to navigating the virtual MakerLab. The male participant already had prior experience working with the content creation tool, while the female participant experienced the content creation tool for the first time during the experiment.

4.3. Procedure

Prior to the experiment procedure, participants were required to fill a pre-test questionnaire that collected demographic information about the participant. Participants were required to prove via photographic evidence that they owned an Oculus Quest or Rift and were gauged based on their prior experience with the MakerLab and the Method of Loci. Alongside this questionnaire was a five-question spatial ability test derived from the "Parallel or Intersecting?" subtest from the Test for Spatial Imagination, developed by Zuzana Juščáková from the Technical University of Košice (Slovakia) [17]. Participants were evaluated out of 6 points on how effectively they could think spatially, out of a precaution concerning spatial ability as brought up by Krokos and co. [9].

Participants were contacted via online telecommunication and engaged in two training sessions to prepare them for the evaluation. The first was an explanation of the Method of Loci and the methodology behind its operation. A paraphrased description of the MoL technique by Yates was provided to both participants [3]. Once participants were confident in their understanding, they were instructed to enter the virtual environment and get accustomed with the content creation tool until they were comfortable in its operation. During this time, participants were exposed to the virtual MakerLab and instructed to also form a loci path that they felt could memorize easily.

During the testing phase, participants were presented with four word lists, each of which consisted of 15 words and contained either high (H) or low (L) imaginable words. These four word lists were derived from Madan's vocabulary list of high imaginable and low imaginable terms [18] (see Appendix) and were presented in an alternating pattern of either H-L-H-L or L-H-L-H. This alternating pattern was required to account for the possible effect of imaginability on recall results with MoL. Furthermore, as the experiment was to test the efficacy of the content creation tool in VR applications of MoL, these four lists also split between allowing and prohibiting the creation tool's use. The order in which the word lists were presented to each participant therefore were randomized in terms of if they started with an H or L word list and if they were allowed to use the creation tool.

During each test, participants were orally provided each term, stated in a sequence of WORD plus SPELLING. For example, if the next word was "Barrel", the experimenter will state "BARREL, B-A-R-R-E-L". Between each word, participants were given fifteen seconds to associate the word with the next loci in their imaginary mental route through the MakerLab. This fifteen second period also gave some time for participants to create objects that acted as referrents for the words if they were allowed to use the creation tool. Each word list reading lasted approximately four minutes as a result. After the word list is stated, the participants were translated to a different version of the MakerLab without the content they created and were instructed to recall the word list items in sequential order to the best of their abilities. Participants were given an infinite amount of time to see if they can recall the order of the words, and participants were measured on the accuracy of the recall order as well as general accuracy of recall without consideration for the word order. Participants repeated this process three more times, totaling to four word lists in total.

4.4. Evaluation

After the test, users were evaluated on their quantitative ability to accurately recall the word item lists, both in regards to order-specific recall and general (non-order-specific) recall. Users were also qualitatively assessed via a post-test questionnaire on how they felt about the experience and if there were any factors to the control scheme and environment that prevented them from engaging in the task. Recordings of each participant's viewpoint inside the virtual environment were taken at each participant's consent.

5 Results

5.1. Accuracy

During the pre-test questionnaire, participant #1 achieved a spatial ability score of 6/6, or 100%. participant #2 achieved a spatial ability score of 5/6, or approximately 83%.

Serial recall accuracy for both order-specific and general accuracy vary wildly between both participants. Participant #1 experienced higher accuracy rates on average when engaged with the creation tool and lower accuracy rates when prohibited from the creation tool. However, participant #2 experienced the opposite accuracy results, showing higher average accuracy when prohibited from the creation tool than when allowed to use the creation tool. This trend appears in both order-specific and in general accuracy. There does not appear to be any significant trend with regards to imaginability and recall accuracy for both order-specific and general recall. Recall rates fluctuate wildly between high and low imaginability word lists when grouped by their modality level (i.e. H-1 and L-1, H-0 and L-0) across both participants.

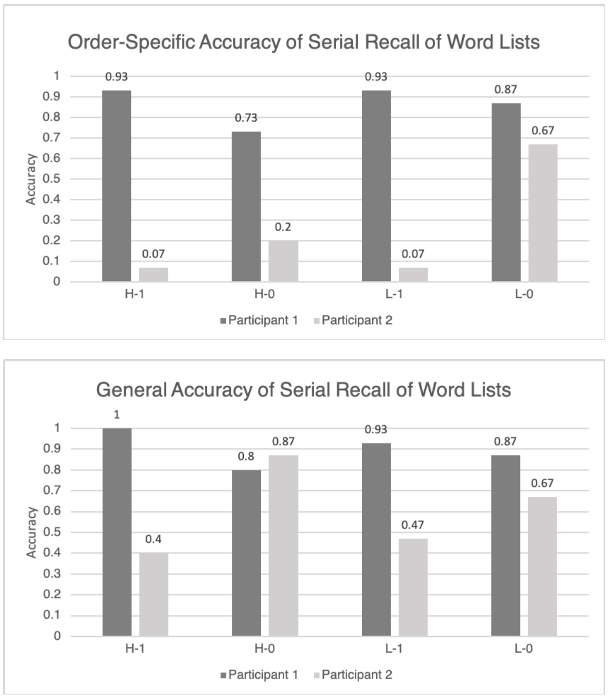

Figure 6: Recall accuracy across both order-specific and general recall for both participants.

With regards to accuracy rate for each individual relative to the order of their test phases, trends in accuracy begin to form. For participant #1, accuracy in both order-specific and general recall drops when participant #1 is prohibited from using the content creation tool. Participant #1 achieved the highest general accuracy in the H-1 word list and the lowest in the H-0 word list, whereas with order-specific accuracy participant #1 achieved the highest in both H-1 and L-1 and the lowest in H-0. For participant #2, the results show a positive trend in accuracy over time. Participant #2 achieved the highest general accuracy in H-0 and the lowest in H-1, as well as the highest in order-specific accuracy in L-0 and the lowest in both L-1 and H-1. While it is possible that participant #2 experienced lower accuracy levels than participant #1 due to a difference in spatial ability, one incorrect answer in the spatial ability test does not correlate strongly with lower accuracy rates.

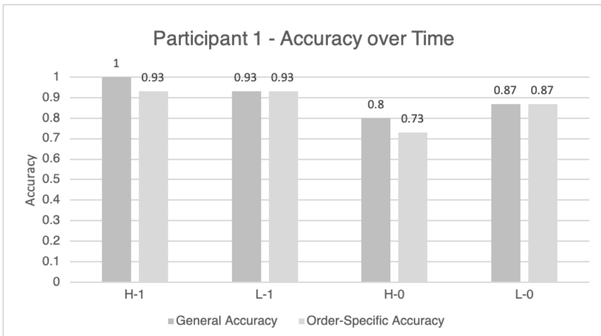

Figure 7: Recall accuracy for participant #1 in the order of their test phases.

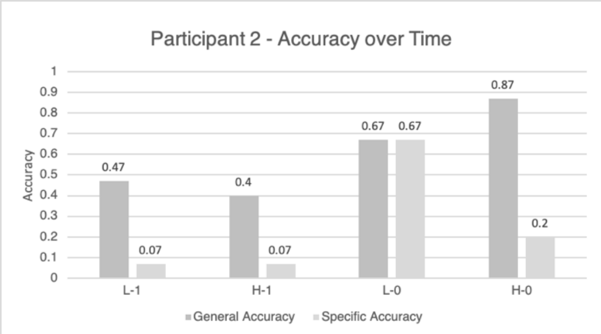

Figure 8: Recall accuracy for participant #2 in the order of their test phases.

5.2. Qualitative Survey

Question	P #1	P #2	Average
How responsive was the environment to actions that you initiated (or performed)?	5	7	6
How natural did your interactions with the environment seem?	1	5	3
How natural was the mechanism which controlled movement through the environment?	5	5	5
How well could you move or manipulate objects in the virtual environment?	1	6	3.5
How much delay did you experience between your actions and expected outcomes?	7	7	7
How quickly did you adjust to the virtual environment experience?	4	5	4.5
How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	5	5	5
How much did the visual aspects of the environment appeal to you?	1	4	2.5
How much did the auditory aspects of the environment appeal to you?	1	7	4
How compelling was your sense of objects moving through space?	6	5	5.5
How compelling was your sense of moving around inside the virtual environment?	5	6	5.5
How aware were you of events occurring in the real world around you?	1	6	3.5
How distracting was the control mechanism?	4	6	5
How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	6	6	6
How much did the control devices interfere with the performance of assigned tasks or with other activities?	3	5	4
How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	7	3	5
How inconsistent or disconnected was the information coming from your various senses?	5	6	5.5
How much did your experiences in the virtual environment seem consistent with your real-world experiences?	5	7	6
To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	6	4	5
How involved were you in the virtual environment experience?	6	6	6
Were you involved in the experimental task to the extent that you lost track of time?	7	5	6

Table 1: **Results from the post-test qualitative survey**
Values range from 1 = negative response, 7 = positive response

Overall, qualitatively the experience of employing the MoL in a virtual environment alongside the creation tool mostly appealed to participants. Participants on average found that the experience was involving and was consistent with what participants may have expected to happen in the real world. No noticeable delays in performance are recorded, and the environment was responsive to user actions.

With regards to the control mechanism in particular, discrepancies occur with regard to the level of control participants felt over objects in the room, and some interference was generated from the creation tool during the participants' tasks. Participant #2 felt particularly distracted with the control mechanism during the task period, which may strongly correlate to participant #2's low accuracy rates while using the creation tool. Furthermore, participant #1 had significant trouble moving and manipulating objects in the virtual world, though this does not seem to have effected participant #1's accuracy rate.

When asked for feedback, participants felt that certain aspects of the creation tool hindered their performance with the MoL technique. Participant #2 mentioned that they felt their performance with the creation tool hurt their concentration due to sometimes unintentionally pressing the wrong button out of instinct, such as pressing the delete button instead of the copy button. Coloring objects also slowed down the creation process due to being mapped to the same joystick that was mapped to movement.

During the testing phase, participants were also observed to have difficulty selecting the prefabs on the palette. At times, participants sometimes hovered their tooltip over the prefab of their choice but did not fully press into the prefab. This ambiguity in the status of the tooltip with respect to prefab selection has produced user errors wherein users think they are creating the prefab of their choice and then have to correct their mistake. Furthermore, ambiguity on the semantic meaning of the yellow grab hover cursor meant that participants were confused about which objects they could re-color, as the target of the recoloring was defined not by closeness to the grab area of the controller but rather the to the tooltip.

6 DISCUSSION

Several key implementation issues with the content creation system have become readily apparent after two experimental cases with participants. These issues stem from both ambiguity in system status and user error caused by differences between what users expected of the system and what the system actually does.

6.1. Limitations

The most prevalent limitation to this study is the lack of participants to perform the experiment with. It must be emphasized that the results of two participants are not representative of the wider population as a whole. A wider participant pool with varying degrees in spatial ability would show a clearer picture as to whether spatial ability amongst users directly correlates with execution of the MoL technique in VR.

A heuristic evaluation of the creation tool in its current form reveals significant problems with regards to the disconnect between user expectation and function alongside ambiguity in system status. While not mentioned among participants, other core issues are also present in the tool such as ambiguous semantic meaning behind buttons on the controller and the general complexity of the creation tool. Because of these problems, this study cannot definitively conclude whether MoL in VR with content creation as a medium is as effective as with more vMoL or cMoL.

Limitations in the test format also have been recognized after a retrospective look at the experimental phase of this paper. A single spatial ability test may not be enough to truly determine people's spatial learning capabilities. Furthermore, no control group with cMoL was tested on, meaning that there is no baseline control to compare this study's implementation of the MoL with.

6.2. Future Work

Should this study be replicated or continued in the future, several changes to the experiment structure and functionality of the content creation tool are highly recommended. A more wholistic pre-test questionnaire that has a more in-depth section for spatial imagination and spatial learning should be utilized, alongside a bigger participant pool divided between different levels of access to content creation and object manipulation in the VR environment.

With regards to the content creator tool, a simpler means of selecting and instantiating objects in the VR world must be explored, alongside a control scheme that is more in line with what users expect from the system. The use of gestures and hand-tracking as selection and manipulation metaphors is a recommended step to take in this regard, though much research would be needed to determine which gestures would feel most natural when instantiating objects and performing other functions such as coloring.

A possible extrapolation of this study could be an investigation into how the level of presence users feel in the virtual world would affect the application of the MoL technique. As presence is highly correlated with natural-feeling user interfaces, a side study could be executed alongside a future test with the content creation system to see if presence affects MoL in VR.

7 Conclusion

This study proposes that the ability to create 3D objects in place of images or other symbols in VR could be as effective as more traditional implementations of the MoL technique. To test for this phenomenon, a content creation tool has been prototyped and been provided to users during an experiment investigating recall ability in VR. Results derived from a 2-participant experiment revealed critical problems in this prototype and have laid the path forward for future developments and further considerations on how to improve its functionality and design.

As a result of these present issues, a conclusive determination about the efficacy of user-created custom objects acting as referents for list items in the Method of Loci technique cannot be made at this time. Future studies that are inspired by this study will have to take special care to update the content creation prototype to improve its user experience and reduce user error.

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References

[1] Bower, G. H. (1970). Analysis of a Mnemonic Device: Modern psychology uncovers the powerful components of an ancient system for improving memory. American Scientist, 58(5), 496–510. https://doi.org/10.2307/27829239

[2] Cicero, M. T. (55 BCE/2001). Cicero on the ideal orator (de oratore)(J. M. May & J. Wisse, Trans.). Oxford, UK: Oxford University Press. https://archive.org/stream/cicerodeoratore01ciceuoft/cicerodeoratore01ciceuoft_djvu.txt

[3] Yates, F. A. (1966). The art of memory. United Kingdom: Routledge and Kegan Paul.

[4] O'Brien, Dominic. "Memory Town System for Languages - Memory Techniques Wiki". mt.artofmemory.com. https://artofmemory.com/wiki/Memory_Town_System_for_Languages

[5] Raz, A.,Packard, M. G., Alexander, G. M., Buhle, J. T., Zhu, H., Yu, S., Peterson, B. S. (2009). "A slice of π : An exploratory neuroimaging study of digit encoding and retrieval in a superior memorist". *Neurocase*. 15 (5): 361–372. doi:10.1080/13554790902776896.

[6] Dalgleish, T., Navrady, L., Bird, E., Hill, E., Dunn, B. D., & Golden, A. M. (2013). Method-of-loci as a mnemonic device to facilitate access to self-affirming personal memories for individuals with depression. *Clinical Psychological Science*, *1*(2), 156–162. https://doi.org/10.1177/2167702612468111

[7] Legge, E. L. G., Madan, C. R., Ng, E. T., & Caplan, J. B. (2012). Building a memory palace in minutes: Equivalent memory performance using virtual versus conventional environments with the Method of Loci. Acta Psychologica, 141(3), 380–390. https://doi.org/10.1016/j.actpsy.2012.09.002

[8] Huttner, Jan-Paul & Robra-Bissantz, Susanne. (2017). An Immersive Memory Palace: Supporting the Method of Loci with Virtual Reality.

[9] Krokos, E., Plaisant, C., & Varshney, A. (2019). Virtual memory palaces: immersion aids recall. Virtual Reality, 23(1). https://doi.org/10.1007/s10055-018-0346-3

[10] Vindenes, J., de Gortari, A. O., & Wasson, B. (2018). Mnemosyne: Adapting the method of loci to immersive virtual reality. In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (Vol. 10850 LNCS, pp. 205–213). Springer Verlag. https://doi.org/10.1007/978-3-319-95270-3_16

[11] Deering, M. F. (1996). The HoloSketch VR Sketching System. *Communications of the ACM*, *39*(5), 54–61. https://doi.org/10.1145/229459.229466
[12] Billinghurst, Mark & Baldis, Sisinio & Matheson, Lydia & Phillips, Mark. (1997). 3D Palette: A virtual reality content creation tool. ACM Symposium on Virtual Reality Software and Technology, Proceedings, VRST. 155-156. 10.1145/261135.261163.
[13] Gravity Sketch. (2019). Gravity Sketch, Video Game.
[14] LaViola Jr., Joseph J. et al (2017). "Chapter 9. System Control." *3D User Interfaces: Theory and Practice*. 4(9): 379-417
[15] Sutcliffe, A., & Gault, B. (2004). Heuristic evaluation of virtual reality applications. In *Interacting with Computers* (Vol. 16, pp. 831–849). https://doi.org/10.1016/j.intcom.2004.05.001
[16] Nielsen, J. (1995). 10 Heuristics for User Interface Design. Retrieved from http://www.nngroup.com/articles/ten-usability-heuristics/
[17] Górska, R. A., & Juščákova, Z. (2003). A pilot study of a new testing method for spatial abilities evaluation. *Journal for Geometry and Graphics*, *7*(2), 237–246.
[18] Madan, C. R., Glaholt, M. G., & Caplan, J. B. (2010). The influence of item properties on association-memory. Journal of Memory and Language, 63, 46–63, http://dx.doi.org/ 10.1016/j.jml.2010.03.001
[19] Gillan, D. J., Holden, K., Adam, S., Rudisill, M., & Magee, L. (1992). How should fitts' law be applied to human-computer interaction? *Interacting with Computers*, *4*(3), 291–313. https://doi.org/10.1016/0953-5438(92)90019-C

APPENDIX

Yate's original definition of the Method of Loci

"It is not difficult to get hold of the general principles of the mnemonic. The first step was to imprint on the memory a series of loci or places. The commonest, though not only, type of mnemonic place system used was the architectural type. The clearest description of the process is that given by Quintilian. In order to form a series of places in memory, he says, a building is to be remembered, as spacious and varied a one as possible, the forecourt, the living room, bedrooms, and parlours, not omitting statues and other ornaments with which the rooms are decorated. The images by which the speech is to be remembered. . . are then placed in imagination on the places which have been memorized in the building. This done, as soon as the memory of the facts requires to be revived, all these places are visited in turn and the various deposits demanded of their custodians. We have to think of the ancient orator as moving in imagination through his memory building whilst he is making his speech, drawing from the memorized places the images he has placed on them. The method ensures that the points are remembered in the right order, since the order is fixed by the sequence of places in the building." (Yates l966, p. 3)

Gordan H. Bower's Nine Salient Aspects of the Method of Loci

1. <u>There is a known list of "cues."</u>
   These "cues", or "loci" must be available to the person at the time list items are studied.
2. <u>The cues are memory images of geographic locations.</u>
   In actuality, neither memory images nor geographic locations are necessary. Presentation of external stimuli such as pictures can substitute for the subject's cueing themselves with memory images. Any readily visualized object or context would supply as good of a loci as an actual geographic location.
3. <u>Cues and items on the list to be learned are to be associated during input of the list items.</u>
   This is the most crucial aspect to the MoL technique. If the person is taught the loci but is not told how and when to use them, no memory improvement is seen. External cues only become effective loci for memory if the subject attempts to associate the loci to list items at the moment the list items are studies
4. <u>Associations are to be made in one-to-one pairings.</u>
   Pairings are actually irrelevant - multiple list items can be attributed to the same loci, for example. However, association of multiple list items is impacted by the subject's ability to simultaneously associate multiple items at once - without such simultaneity, the learning of later items impacts the recall of earlier-learned items. Furthermore, the association of multiple items to one cue may impact serial recall of the ordering of the list items in particular.
5. <u>Associations are to be effected through imaginal elaboration, specifically by use of visual imagery - in other words, use imaginal elaboration, especially visual imagery.</u>
   This is also the most crucial aspect to the MoL technique. Imaginal elaboration, or the depiction of relationships via referent objects or imagery between the loci and the list item, is critically important. The imagery has to be of concrete objects or visual referents, not to the words themselves. For example, associating a word (ex. tomato) with a loci (ex. doorway) is not enough - a referent (ex. Tomatoes are splattered across the doorway) is necessary.
6. <u>The imaginal construction should be unusual, bizarre, striking.*</u>
   The correlation with unusual imagery and memorization is entirely negative - the "bizarreness" of imagery does not improve or reduce the learning effect of the MoL technique.
7. <u>If the list items are studied a second time, the same items should be placed at the same loci; even if ordered output is not required, constant ordered input is desirable.</u>
   If multiple trials are performed on the same list, then list items must be associated with the same loci. If the serial ordering of the list items is not necessary, then the experimenter is allowed to mix up the order of the list items, but the list items themselves must be associated with the same loci regardless.
8. <u>At the time of recall the person must cue his recall of the list items.</u>
   The subject must have access to their cues in some manner during the recall testing period.
9. <u>The recall cues must be the same as or similar to those he thought of while studying the items.</u>
   An example: if Loci A has been associated with list item B, then an effective Loci A' for retrieving list item B from memory must be close in semantic meaning (ex. Synonymous, or within the same category of images).

Sutcliffe and Gault's heuristic evaluation guidelines for virtual reality applications

1. Natural engagement. Interaction should approach the user's expectation of interaction in the real world as far as possible. Ideally, the user should be unaware that the reality is virtual. Interpreting this heuristic will depend on the naturalness

requirement and the user's sense of presence and engagement.
2. Compatibility with the user's task and domain. The VE and behaviour of objects should correspond as closely as possible to the user's expectation of real world objects; their behaviour; and affordances for task action.
3. Natural expression of action. The representation of the self/presence in the VEshould allow the user to act and explore in a natural manner and not restrict normal physical actions. This design quality may be limited by the available devices. If haptic feedback is absent, natural expression inevitably suffers.
4. Close coordination of action and representation. The representation of the self/presence and behaviour manifest in the VE should be faithful to the user's actions. Response time between user movement and update of the VE display should be less than 200 ms to avoid motion sickness problems.
5. Realistic feedback. The effect of the user's actions on virtual world objects should be immediately visible and conform to the laws of physics and the user's perceptual expectations.
6. Faithful viewpoints. The visual representation of the virtual world should map to the user's normal perception, and the viewpoint change by head movement should be rendered without delay.
7. Navigation and orientation support. The users should always be able to find where they are in the VE and return to known, preset positions. Unnatural actions such as fly-through surfaces may help but these have to be judged in a trade-off with naturalness (see heuristics 1 and 2).
8. Clear entry and exit points. The means of entering and exiting from a virtual world should be clearly communicated.
9. Consistent departures. When design compromises are used they should be consistent and clearly marked, e.g. cross-modal substitution and power actions for navigation.
10. Support for learning. Active objects should be cued and if necessary explain themselves to promote learning of VEs.
11. Clear turn-taking. Where system initiative is used it should be clearly signalled and conventions established for turn-taking.
12. Sense of presence. The user's perception of engagement and being in a 'real' world should be as natural as possible.

Word Lists, adapted from Madan et al.

Category	Word List Items (Randomized)
H-1 (High-imaginability, content creator allowed)	1. Barrel 2. Sponge 3. Isle 4. Toilet 5. Card 6. Cigar 7. Lock 8. Prince 9. Rocket 10. Onion 11. Salt 12. Hammer 13. Bone 14. Flame 15. Tail
H-0 (High-imaginability, content creator prohibited)	1. Tank 2. Rope 3. Lace 4. Helmet 5. Cabin 6. Deer 7. Eleven 8. Basket 9. Parcel 10. Skull 11. Stool 12. Queen 13. Gift 14. Meal 15. Aisle
L-1 (High-imaginability, content creator allowed)	1. Ratio 2. Aide 3. Coup 4. Shroud 5. Fund 6. Quote 7. Pause 8. Wishes 9. Trust 10. Plea 11. Greek 12. Muck 13. Brief 14. Rumour 15. Event
L-1 (High-imaginability, content creator prohibited)	1. Urge 2. Claim 3. Bliss 4. Dread 5. Treaty 6. Prince 7. Remark 8. Health 9. Phrase 10. Score 11. Queue 12. Gale 13. Fare 14. Output 15. Excuse