Optimizing Virtual Reality-based 'Method of Loci' Memorization Techniques Through Increased Immersion and Effective Memory Palace Designs

A Thesis

presented to

School of Applied Computing, Faculty of Applied Science and Technology

of

Sheridan College, Institute of Technology and Advanced Learning

by

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in partial fulfilment of the requirements

for the degree of

Honours Bachelor of Computer Science (Mobile Computing)

December 2020

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Submitted to the School of Applied Computing, Faculty of Applied Science and Technology
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Abstract

For most, an improvement in memory would always be desirable, whether that be said from the point of view of an aging individual with declining memory performance or from the perspective of someone seeking to memorize mass amounts of information in a small amount of time. One such way for people to improve upon their memory performance is by learning to make use of the ‘method of loci’ (MoL), a famously complex, ancient memorization technique for non-spatial information recall. With the use of virtual reality technology, this technique can finally be easily taught to individuals for use in their daily lives. In this thesis, exploration into this avenue of using MoL in virtual reality is furthered by experimentation into how the technique can be optimally used. In order to determine which variables of the virtual memory palace can be adjusted to optimize recall performance in participants, a literature review is conducted on related experiments in the field. According to observations from multiple studies, a new virtual memory palace is designed and put to use. It is discovered that through a single, limited use of a new memory palace design that aims to improve upon designs in other studies and optimize memory recall performance, that participants are able to remember approximately 20.4% more non-spatial information on average, when compared to traditional memorization techniques used by participants. After a second use sometime later, participants improve, remembering 22.2% more non-spatial information on average. This suggests that the virtual memory palace experience can be optimized to produce significant improvements in recall performance with very little memorization and training time.

Keywords: virtual reality, memory, method of loci, psychology, cognitive science, improving memory recall, memorization.

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Title: Director, Centre for Mobile Innovation

Acknowledgments

I would like to thank Professor Ed Sykes for guiding me through the long thesis process. Furthermore I would like to thank those of my family and friends who helped with gathering experimental results during the unprecedented time of COVID-19, and specifically my brother, Tyson M., for creating the 3D architecture required for the apartment used as the location for the virtual memory palace.

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Chapter 1

Introduction

In this thesis, an investigation was conducted into designing and evaluating the 'Method of Loci' (MoL) in a Virtual Reality (VR) setting. *Loci* is the plural form of the Latin word for 'locus', which means 'place' (Yates, 1999). The MoL is an ancient memorization technique known by many to be one of the most powerful ways available for people to memorize non-spatial information by making use of the powerful spatial memory abilities exhibited by humans. It was used by ancient Greek and Roman orators to remember lengthy portions of text. A sample visualization of the technique can be seen in Figure 1-1. Usage of the technique dates as far back in time as ancient myths such as in the story of Simonides of Ceos (Yates, 1999).

In that myth, Simonides uses the MoL to remember the faces of various recently deceased people by imagining each of their seats at a table of a banquet hall. The technique makes use of the ability for a human to remember things based on places they have visited, and things they have seen, by asking the user of the technique to imagine a building in their mind, like a palace or a place from their past. Then, they are told to 'place' the different things they need to remember throughout this virtual building. Using a path defined by the memorizer through the imagined structure, the participant is able to remember everything s/he wanted to by simply finding 'where' the memories were placed.

A significant number of studies have been done developing this traditional mnemonic technique into a virtual or augmented reality (VR or AR) experience (R. Raso & Loos,

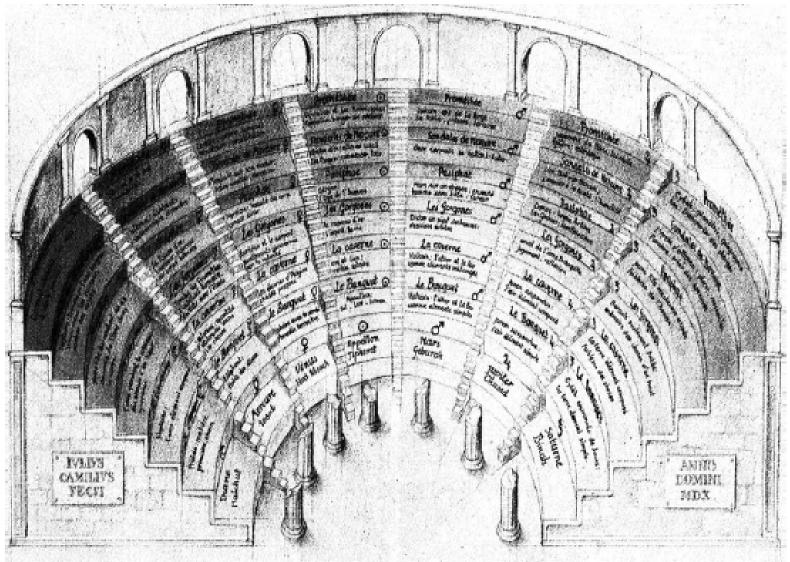


Figure 1-1: Depiction of a Memory Palace from 1511 AD, by Giulio Camillo (Krokos et al., 2019).

2019; Huttner, Qian, & Robra-Bissantz, 2019; Liu et al., 2019; Huttner, Robbert, & Robra-Bissantz, 2019; Krokos et al., 2019; Huttner & Robra-Bissantz, 2017; Peeters & Segundo-Ortin, 2019; Huttner et al., 2018; Vindenes et al., 2018; Bhandari, 2019). One of the primary goals of these studies has been seeing how VR head-mounted displays (HMDs) perhaps increase the effectiveness of the MoL technique. In several papers it was already shown that people remember things more effectively with the traditional MoL, and now comparisons have been made to a potential VR application of the technique. Research has shown VR enhancing the memorization process has significant potential, but more research is needed (Krokos et al., 2019; Reggente et al., 2019; Peeters & Segundo-Ortin, 2019; Huttner, Robbert, & Robra-Bissantz, 2019; Huttner & Robra-Bissantz, 2017). The use of Virtual Reality MoL has already been shown to encourage people and increase people's confidence in using the technique (Peeters & Segundo-Ortin, 2019; Perera R. M & S.H.D, 2019; O'Grady & Yildirim, 2019; Huttner, Qian, & Robra-Bissantz, 2019).

In this research, these ideas of exploiting VR and MoL are taken a step further. Past studies have not, for the most part, given participants full immersion into the

MoL experience, so there was an aim to heighten immersion as much as possible in this work. This increased immersion is said to strengthen memory recall (Huttner, Robbert, & Robra-Bissantz, 2019; Krokos et al., 2019; Huttner & Robra-Bissantz, 2017). By giving participants the opportunity to reach out and place objects with their actual arms, walk using their own legs, hear sounds in the virtual world and be fully immersed in the virtual experience, it was postulated that this would have a positive impact on the effectiveness of the MoL such that it would result in better memory recall when memorizing non-spatial information.

The main comparison made was between a pre-test and post-test condition. In the pre-test condition, participants were able to use whatever mnemonic technique they wished to remember information in the form of a word list. In the post-test condition, they were instructed on use of the MoL and made use of a newly designed and optimized virtual memory palace based on multiple other studies' observations. It was expected that a significant increase in memory recall performance would be observed in the optimized virtual memory palace scenario.

While the traditional MoL has been shown to increase memory recall performance for quite some time (Yates, 1999), it has always been considered complex and requiring much training for one to learn and use the technique effectively (Mccabe, 2015; Huttner, Qian, & Robra-Bissantz, 2019; Huttner & Robra-Bissantz, 2017; Reggente et al., 2019; Legge et al., 2012; Huttner, Robbert, & Robra-Bissantz, 2019). Many attempts have been made with and without HMDs to try and virtually simulate the memory palace of the MoL in order to lessen cognitive load of memorizers and make the technique more encouraging and accessible to all people. It is however an outstanding question in the field of cognitive science, memorization, memory recall and VR as to whether a virtual MoL technique can be impactful enough on recall performance in a short enough time for people to consider seriously using the MoL in their daily lives (Huttner, Qian, & Robra-Bissantz, 2019; Bhandari, 2019; Huttner, Robbert, & Robra-Bissantz, 2019; Putnam, 2015).

By designing a virtual memory palace in a way optimized for maximum memory recall performance based on the suggestions from multiple other studies, it was postulated that such a system could enhance the overall recall performance of people, especially when recalling non-spatial information. Increasing the use of the MoL in VR will have some concrete benefits such as mitigating memory issues caused by old age or mental deficiencies (Ijaz et al., 2019; S. Manivannan & Zaben, 2019; Montana et al., 2019; Sayma et al., 2019; Wiederhold & Riva, 2019).

The proposed system could be used by people to train and improve their cognitive abilities, and may also be useful for students who wish to memorize information easily. Teachers also could use VR MoL in the classroom to teach the MoL mnemonic technique and encourage students to use it effectively to enhance their memory of subject material (Peeters & Segundo-Ortin, 2019; Huttner, Robbert, & Robra-Bissantz, 2019). The projected research results from this work may show just how effective the MoL is and that could make the technique vastly more desirable by people who are stubborn about trying new things like reworking how they memorize non-spatial information entirely.

Further benefits of this research beyond what has been found so far, with the help of strong virtual immersion (with the use of modern VR technology) as well as trying to discover an optimized way to envision and use a virtual memory palace, may be the key to finding out how best the ancient memorization technique, the method of loci, could be used by everyone.

1.1 Thesis Statement

An optimized VR MoL experience developed with heightened immersion and design suggestions from a multitude of similar studies under specific, well-defined conditions, will produce significantly better recall results than memorization techniques used by participants in their daily lives as-is.

1.2 Outcomes and Contributions

Through this research, an experiment was performed with human participants after designing a virtual MoL environment in Unity to be used in VR (on an Oculus Rift S), with the addition of sensors on the ankles and waist to simulate real walking movements (KAT VR's "KAT Loco" sensors). The system created allowed experimental information to be collected regarding memory performance of the participants under differing sensory stimuli aimed to increase immersion and thus strengthen memories in the virtual memory palace, and that information is presented in this thesis. A discussion of these results and the possible future research avenues in this field of study are included.

Chapter 2

Literature Review

2.1 Traditional MoL

Generally, knowledge of the traditional method of loci stems from the book, *The Art of Memory*, by Frances Yates (Yates, 1999). Referenced multiple times throughout many found studies, it is a source of information about the history of people using the method from ancient times, through until medieval times, all the way until modern day. The technique originates from ancient Greek roots, where it was used by orators to memorize particularly lengthy speeches.

It was specifically an inspired technique said by the poet Cicero to be from the ancient story of Simonides of Ceos (Yates, 1999), who used it at a destroyed banquet hall. After being asked to go outside for a moment, the building collapsed behind him and killed those inside. Their bodies were left in such a condition that their families did not know who was who. Using the MoL, Simonides was able to remember the faces of these people, associated with seats at the banquet table, and determine which bodies belonged to which people.

The technique involves picturing one's self in a place (also known as the memory palace) that is known particularly well by the memorizer. Once prepared, knowing what they want to memorize, they imagine moving through the place in a particular path, placing things they wish to remember in various places throughout the palace. After the exercise, when they wish to recall the information, the memorizer merely recalls the place and walks through it the same way again in their mind, looking to the places they placed memories to remember each of them. Various advice for creating memory palaces was taken from the traditional method (Yates, 1999) and summarized for later effective use (Fassbender & Heiden, 2006):

- The space should be solitary and not very crowded;
- Distance between loci should be at least 10 meters;
- A unique sign should exist every 5th loci;
- Repetitive environments should be avoided;
- Loci should not be too spacious or too narrow; and
- Loci should not be too bright or too dark.

Since this tale, people have tried to replicate the technique, using the idea of linking images to locations (loci, the plural of locus [location]) that befit them to try to remember the images themselves or whatever information those images possess. More recently, people have tried to combine the mnemonic technique with the benefits of virtual reality.

2.2 VR & MoL in Education

The MoL has obvious applications in the realm of education – as a tool for students to memorize information that they are in the process of studying. Although seldom used due to its high complexity, the reputation of the MoL's high effectiveness shows its great potential. A significant number of studies have been done regarding investigation of the technique's effectiveness, and it has been used widely by memory champions to remember extremely large amounts of information.

Virtual reality has also shown great potential for educational use (Lee & Wong, 2014; Huttner, Qian, & Robra-Bissantz, 2019; Reggente et al., 2019; Huttner et al., 2018; Huttner, Robbert, & Robra-Bissantz, 2019). While VR is now generally thought of as solely when virtual environments are simulated through an HMD (head-mounted display), not long ago were virtual 3D environments all considered under the umbrella of VR. When HMDs were more expensive and not as wide-spread, studies were done into whether VR on desktop monitor displays could be used to augment education.

One study used a 3D frog surgery simulation on a monitor to try to teach participants about biology and compared their recall of the content to those who learned the content through a traditional paper-based format (Lee & Wong, 2014). People learned things more effectively from the controlled virtual environment as a whole, but authors came to the conclusion that it was likely people with differing levels of spatial ability would benefit from the virtual simulation more or less so. This suggests importance in analyzing participant spatial abilities before considering their results in these kinds of studies. It was also believed that people learned better because the simulation took cognitive load off of participants.

Multiple other studies came to the conclusion that, when they tried to combine virtual reality with the MoL specifically, there was great potential usage in education for both students and professors (Huttner, Qian, & Robra-Bissantz, 2019; Reggente et al., 2019; Huttner et al., 2018; Huttner, Robbert, & Robra-Bissantz, 2019). In one of these studies there was particular potential shown for VR MoL reducing mental complexities to their minimums and even allowing those that would have a hard time learning to use MoL, use the technique regardless (such as people in elementary school) (Huttner, Qian, & Robra-Bissantz, 2019).

2.3 VR & MoL in Therapy, Recovery, and Intervention

VR and the MoL have been shown to be useful in multiple studies for helping people recover from injuries or losses, and overcome mental disabilities or deficiencies (Montana et al., 2019; Sayma et al., 2019; S. Manivannan & Zaben, 2019; Wiederhold & Riva, 2019; Ijaz et al., 2019; Optale et al., 2010). One of these studies looked into how

VR environments are useful for neurorehabilitation, allowing participants to improve their spatial memory through training (Montana et al., 2019). It was shown that VR training sessions are most effective when done over multiple, long, intense sessions. Interestingly, results also point towards the conclusion that the more immersive an environment is, the better the environment is for spatial memory improvement training. Sayma et al. (2019) also supports this idea on the benefits of immersion.

In another study, an experiment included adapting VR to be a memory testing tool for older folks that are at risk of or have dementia related mental issues (Ijaz et al., 2019). Using an Oculus Rift headset in combination with a joystick controller, participants were instructed to explore a real world environment prepared with Google Maps 3D street view. The group was compared against a group using Google Maps on a traditional screen. With the VR, it was found that participants have better memory assessment outcomes than the desktop monitor screen group. Again, these results support the idea that further immersion leads to more effective memory recall. Optale et al. (2010) had a similar experiment that led to the same observed general outcomes after participants were trained to use a VR interface with a joystick over the course of multiple weeks of sessions.

The MoL has also specifically been shown useful for therapy, recovery, and intervention. In one particular study, people with depression were asked to use the MoL to try and store pleasant memories in their memory palaces for later retrieval (Dalgleish et al., 2013). It had already been displayed by multiple other studies that allowing people with depression to more easily access positive memories would help them recover and feel happier overall. Results from this study showed that the exercise made it much easier for people to access their positive memories during depressing periods of time (Dalgleish et al., 2013).

2.4 Traditional MoL Experiments

Many studies have been done exploring the MoL's ability to help people remember large amounts of information (Mccabe, 2015; Kroneisen & Makerud, 2017; Verhaeghen

& Marcoen, 1996). Although the technique makes use of the human mind's great spatial memory performance, generally these experiments involve having participants memorize lists of words to test their recall. With high potential in education and medical fields, there is plenty of motivation for the research at this time.

Three particular studies into traditional MoL (no virtual environment involved) are reviewed here: Mccabe (2015); Kroneisen & Makerud (2017); Verhaeghen & Marcoen (1996). In the first of these (Mccabe, 2015), students are instructed to use the MoL to remember grocery items, with the hopes of having them integrate the mnemonic technique into their daily lives for potential memory recall improvement. Results were promising, and suggested that MoL could be used in one's daily routine for an overall improvement in memory, for not only students, but anyone (Mccabe, 2015).

In Kroneisen & Makerud (2017), the MoL was compared in performance against survival processing, a phenomena where humans will recall survival related information quite easily when faced with a survival situation, the MoL was either shown to be just as effective or even better, in all situations. Only when words had high imageability (how easily one can imagine how the word 'looks'), did survival processing do as well as the MoL.

In the third study, Verhaeghen & Marcoen (1996) used the MoL to try and improve memory recall in both young and old participants while investigating brain plasticity for different age groups. Conclusions suggested that the older participants were generally less compliant and would use the MoL less often or improperly even when instructed to do otherwise, and possibly as a result, had worse recall than younger participants. It is therefore important to be mindful of ages of participants in future studies of the MoL.

2.5 Alternative Implementations of Virtual MoL

Before describing use of HMDs to augment the effects of using the MoL, it is important to describe other approaches that have been used in the field to simulate virtual

Figure 2-1: Some devices used in other virtual memory palaces (From left to right: Monitors/TVs, Cristaleyes Glasses, Smartphone HMDs, Oculus Rift, HTC Vive).

environments for the technique. Various devices used by different studies to simulate a virtual memory palace are shown in Figure 2-1. Six papers were studied that used desktop monitor style displays to simulate the MoL: Fassbender & Heiden (2006); Jund et al. (2016); Legge et al. (2012); Das et al. (2019); Caplan et al. (2019); Reggente et al. (2019), and one paper made use of augmented reality (AR) (R. Raso & Loos, 2019).

2.5.1 Monitor Display-based Virtual MoL

One of the earlier examples of virtual MoL is from 2006 (Fassbender & Heiden, 2006), when an environment was simulated on a monitor similar to how one might play a first-person shooter game. Using advice from traditional MoL texts (Yates, 1999), a memory palace was designed for participants that allowed them to place different objects that needed to be remembered throughout the palace (Fassbender & Heiden, 2006). After this process, each participant was tested on their recall of the items placed at different loci. Their performance was compared against memorization off of a piece of paper using similar words and whatever technique a participant wished to use.

The environment made use of appropriate sounds when placing each item to be remembered in the palace, to try and make more intense and involved memories. This was done in the belief that more immersion through multiple sensory outputs would lead to better memory recall. The authors suggest future MoL research to try and have to-be-remembered items displayed unlike what participants expect, as the traditional technique suggests that the human brain remembers unique and non-repetitive environments and items more easily (Yates, 1999).

In another study (Legge et al., 2012), three groups of participants used MoL in the traditional sense, in a virtual environment on a desktop monitor screen, and memorized using any memory technique they wished. Both MoL groups had substantially better recall of items compared to the uninstructed group (Legge et al., 2012). However, both MoL groups had similar performance. It is important to note that traditional MoL involves using an environment for the memory palace that is very familiar to the participant (Yates, 1999), whereas virtual MoL makes use of a pre-made environment completely unfamiliar to the participant (unless the environment was modeled based on a real-world location, but this is rarely done) aside from the small amount of training directly before testing.

Being mindful of the lacking familiarity of the environment and training, it becomes quite impressive that the two groups still had similar performance and suggests that if the virtual MoL group was given enough training over multiple weeks or so to get used to a virtual environment to the point where they were as familiar with it as the traditional participants were familiar with their environment, the virtual MoL group might even do better than the other group at recalling information. The authors expressed other benefits with virtual MoL environments: They are easy to control and restrict for experiments, require less training to use, and as evidenced by other results of their experiment, people are more compliant with the virtual MoL than the traditional approach (Legge et al., 2012). There are multiple studies that support this point, where participants feel quite encouraged and even more confident after using the virtual MoL.

2.5.2 Virtual MoL Compared to Other Frames of Reference and Mnemonic Strategies

One study (Jund et al., 2016) investigates the difference in recall performance between egocentric and allocentric frames of reference. Egocentric was represented by placing items to be remembered in a row across a large display, whereas allocentric was represented with a virtual MoL experience on the same screen in front of the participants. Surprisingly, the egocentric frame of reference was shown to perform better than the allocentric virtual MoL. There are several points that need to be considered here with this study however that could contribute to this outcome: Immersion was low since there was no HMD available, participants could not move freely in the first of the two experiments in the study, they could not physically interact with the environment in a life-like way either, and lastly, as talked about by the authors, knowledge of the architectural environment when using the MoL is very important to using the technique correctly.

More recently, the MoL was compared against other peg mnemonic strategies for memory recall (Caplan et al., 2019). The authors wanted to determine whether imagining navigation was truly crucial to the MoL. Using virtual MoL with relatively low immersion, done with a mouse and a desktop monitor display, participants were instructed to use three different pre-made virtual environments they were unfamiliar with that had vastly different architectural designs. Results seemed to suggest that the MoL did not benefit directly from imagined navigation when performance between the three environments had very little difference (Caplan et al., 2019). The different environment blueprints and screenshots of them can be viewed in Figure 2-2.

The environment based on an apartment had better recall results for people than the two other more abstractly designed environments, and this is hypothesized to be because people were more familiar with the general structure of an apartment (Caplan et al., 2019). This provided motivation for choosing to create a memory palace design with an apartment-like layout in this thesis. Furthermore, the performance of participants was similar to average performance of people recalling information with other mnemonic techniques (Caplan et al., 2019). In this experiment, immersion was once again lacking, and participants were made to memorize lists of only 20 words, whereas other papers suggest at least 40 words to really show the benefits of the MoL (Huttner, Robbert, & Robra-Bissantz, 2019).

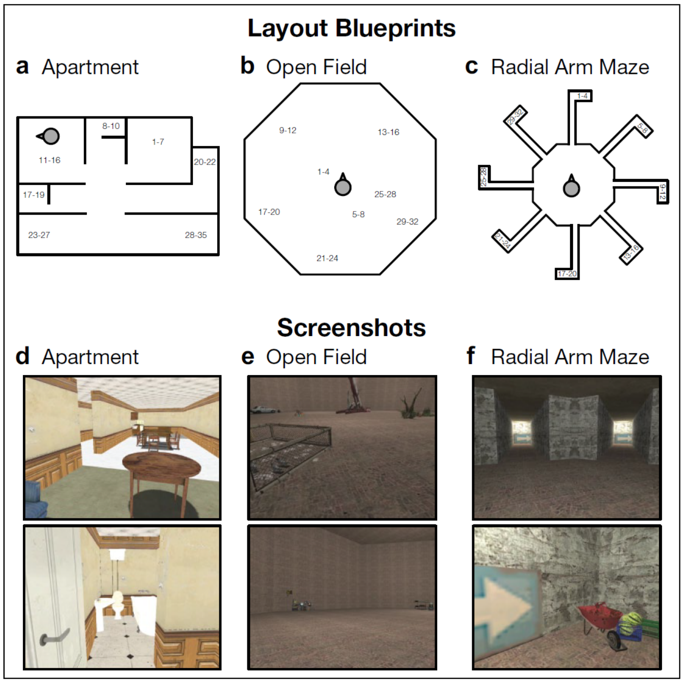


Figure 2-2: Memory Palaces Layout Blueprints and Screenshots from Caplan et al. (2019).

2.5.3 Adding Environmental Interaction to Virtual MoL

There was also a study that investigated use of an HMD (an older version of the Oculus Rift), but found that people were nauseous when using it in many cases, so they decided against using one (Reggente et al., 2019). It is possible that this was due to the less recent HMD, and/or the software being used for the simulation, *OpenSimulator*. The experimental group is given the ability to freeze objects to be remembered in place in front of them, and the other group simply finds the objects scattered throughout multiple environments. The experimental group was also specifically instructed on how to use the MoL in the classical style, whereas the other group was told they were using a proven technique for memorization, exploring environments without knowing what to do.

The authors talk specifically about how the brain seems to have been evolved in a way to support memorization of purposeful navigation, so it is important to be included in MoL experimentation (Reggente et al., 2019). While this research had a short training period for its participants, it was recommended to have a longer one, especially if one wants to observe the long-term memory effects of the mnemonic technique (Reggente et al., 2019). Tokens are collected by the participants in each environment before memorization tasks in order for them to become familiar with the environment they are in, which is a crucial step in the MoL. Only 15 objects are memorized in each environment.

The varied environments, rather than keeping participants in one single virtual world, seem to be counterproductive. Generally, giving more exploration time for a single place seems to be a more effective approach as it makes participants more familiar with it and could increase memory performance that way (Reggente et al., 2019; Caplan et al., 2019; Jund et al., 2016). It was suggested by the authors that future studies should investigate learning other types of information rather than just simple lists, to be more relevant to a possible educational application (Reggente et al., 2019).

2.5.4 Unique Virtual MoL Applications

In Das et al. (2019), inspiration from virtual MoL is used to create a new authorization method for smartphones, an application of the method that shows its potential. Users of the phones would, rather than using a code to unlock their device, move through a path in a large virtual environment. The results suggested that it was significantly more effective than traditional unlocking options for phones, especially in situations where people needed to remember a code for a device that they rarely use (Das et al., 2019).

Lastly, in R. Raso & Loos (2019), augmented reality (AR) is used rather than virtual reality to use the MoL technique for memorizing information. Participants in the study literally walk around to explore the information seemingly projected onto the ground with the Microsoft HoloLens, and the authors believe that this exploration option could offer an advantage compared to a virtual reality MoL environment. It is important to note that, as will be done in this thesis, one can make use of ankle/waist sensors, a low friction platform with sensors, or a specific kind of treadmill, to have

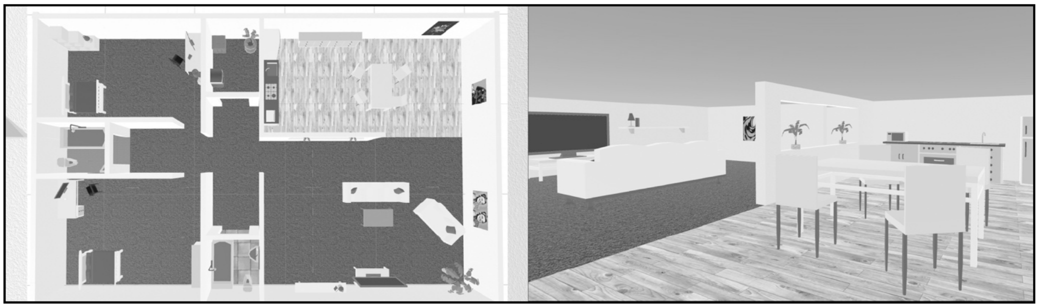


Figure 2-3: Memory Palace from Huttner & Robra-Bissantz (2017).

realistic walking be simulated in a VR environment without needing any space at all. Also, AR environments, since they consist of holograms on top of reality, can be very dense with distractions that would take participants' minds off of their memorization tasks.

2.6 VR MoL Experiments

Nine studies were reviewed out of the many that have been written that investigate virtual MoL environments used with the added immersion of an HMD.

2.6.1 Transitioning to HMDs from Monitor Displays

In the earliest example reviewed (Huttner & Robra-Bissantz, 2017), participants used virtual MoL twice, but first used the now traditional desktop monitor screen setup while on the second attempt at using the MoL, they used an HMD to simulate the virtual environment more immersively. Recall results leaned towards VR via HMD being more effective (Huttner & Robra-Bissantz, 2017). Participants were also found to be more compliant with using the HMD virtual environment over the desktop monitor screen environment. The palace created for this study can be seen in Figure 2-3.

Multiple other studies are reviewed in this one, and there is support for the idea that long-term memory may benefit even more from the MoL since it is thought to be more effective when participants are familiar with the environment used (Reggente et al., 2019; Caplan et al., 2019; Jund et al., 2016; Yates, 1999). It was suggested by the authors that future studies with virtual MoL should make use of audio cues for added immersion, such as footstep noises when a participant walks. It is important to note that this paper's experiment used a smartphone-based HMD, so it would normally be considered an HMD with low immersion when compared to others.

A second study (Krokos et al., 2019) also compares virtual MoL recall performance between usage on a desktop style screen and an HMD. In this study, unlike most that test with a list of words, the participants were asked to remember the names and faces of various famous people in two different virtual environments, the motivation driven by the MoL's traditional use to memorize images that represented information (Krokos et al., 2019; Yates, 1999). Figure 2-4 shows this unique form of memorization in a virtual memory palace.

People in the experiment could not move or place images, but only had the option to look around from the perspective of something like a 360 degree camera, to see if that small factor of immersion would be enough to improve memory recall. Results suggest that indeed, any form of immersion helps memory recall, and the literature review included in the study also points towards this conclusion (Krokos et al., 2019).

Immersiveness is again praised as a factor for improved memory recall in Huttner et al. (2018), where people are found to recall information better in virtual MoL when items to be remembered include not only the text of a word to be remembered, but an image too, following the idea of dual coding theory. It was recommended that future research should delve into animating items to be placed, trying to use audio cues and videos, or any other types of media, to see how they affect memory recall performance.

2.6.2 Spatial Cognitive Ability Impacting VR MoL Performance

A system called Mnemosyne is created in Vindenes et al. (2018) based around the popular idea that immersiveness is key to memory recall performance with the virtual

Figure 2-4: Memory Palace from Krokos et al. (2019) – Memorization of faces rather than words.

MoL, and there comparisons are made between traditional MoL, monitor display MoL, and VR MoL. Mnemosyne can be seen in Figure 2-5. Results were opposite of what the researchers predicted, with traditional MoL surprisingly having the best performance (Vindenes et al., 2018).

However, it was also observed through a spatial cognitive test completed before the experiment, that those in the traditional MoL group had the best spatial cognitive ability (Vindenes et al., 2018). Performance was directly correlated with the spatial cognitive ability of a participant, and showed that it is crucial to divide people into groups in these experiments so that there is an even balance of spatial cognitive ability since certain people will naturally memorize information better (Vindenes et al., 2018). Again, this was a study that used a smart-phone based HMD, so the immersiveness could be much higher.

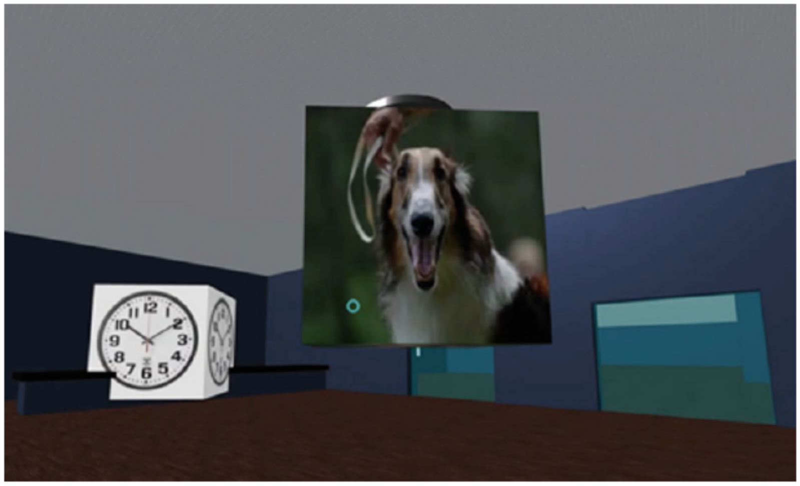


Figure 2-5: Mnemosyne Memory Palace from Vindenes et al. (2018).

2.6.3 Smartphone HMD Observations in Virtual MoL

Two other studies were also found using smartphone HMDs. The first of these (Huttner, Qian, & Robra-Bissantz, 2019) looked into whether participants needed the MoL explained to them or not for the experiment to be effective, and results were promising, showing a high potential for participants to not actually need to know much about the technique for memorization to happen. Simply exploring the virtual environments was sufficient. The authors saw this as potential for educational applications of VR MoL.

In the other study (Huttner, Robbert, & Robra-Bissantz, 2019), authors also come to the conclusion that high immersiveness in environments leads to better recall when using VR MoL after reviewing other research. It is said here that 40 words seems to be a good minimum number for showing the true potential of the MoL technique. There is also support from this research for the idea that longer training times are needed for virtual MoL, highlighting the importance of the environment being familiar to participants. A screenshot from this environment can be seen in Figure 2-6.

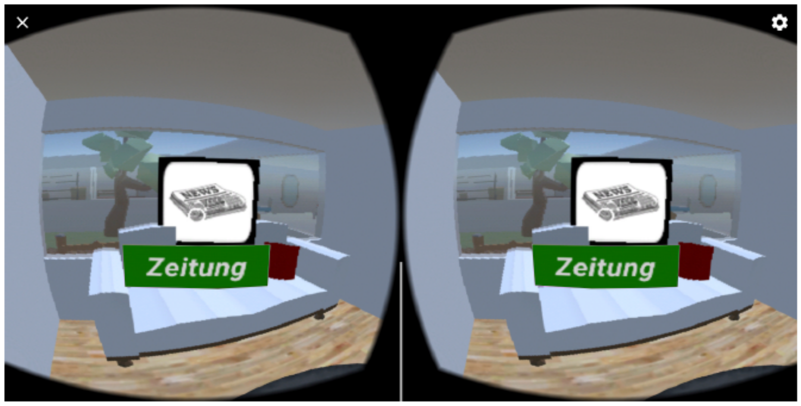


Figure 2-6: Memory Palace from Huttner, Robbert, & Robra-Bissantz (2019).

2.6.4 Highly Immersive HMDs and Memory Palace Design Considerations

Two papers were found that used an HMD that was more immersive than a smartphone, both opting to use the HTC Vive (Liu et al., 2019; Bhandari, 2019). In Liu et al. (2019), a pilot experiment is described where people can walk naturally unlike most research done before, using an allotted space in real life that matches the size of the rooms in the virtual memory palace. They could also reach out with controllers in each hand to interact with the environment, but items to be remembered were pre-placed throughout, so this interaction was seen by participants to be useless.

The rooms all have identical size, and changing between rooms was suggested by the participants to be confusing considering there was no walking transition (the rooms used the same real-world space), and because the rooms were structured so similarly despite each one having a different visual theme. This memory palace design is shown in Figure 2-7. The results were not very encouraging, but the researchers admit that there was likely not enough training time for people to get familiar with the environment (Liu et al., 2019).

It is important to note that traditionally the MoL has been seen to work best with unique environments that are non-repetitive, and ones with an abundance of space between items to be remembered, and there are other possible reasons that the results were not as great as they could have been. The other study was done using

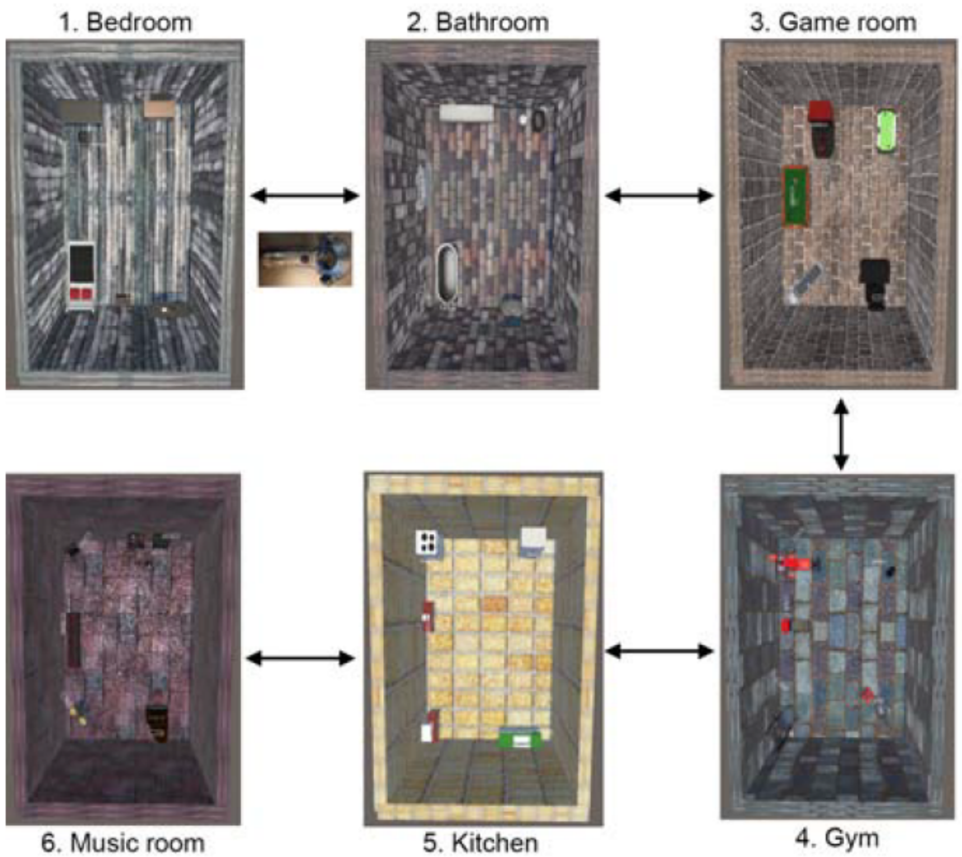


Figure 2-7: Memory Palace Design from Liu et al. (2019).

Figure 2-8: Memory Palace Inspired Environment from Bhandari (2019).

an HTC Vive Pro HMD and an Xbox controller for navigation (Bhandari, 2019). An experiment involving a large simulated tropical environment for participants to explore based upon the concepts of the MoL was included. This simulated environment is shown in Figure 2-8.

Participants were made to memorize large amounts of floating text, were given paths of coins to collect for exploration of the area, and also had a 3D sound experience to further immersion (Bhandari, 2019). The author recognizes that manual placement of information would likely have increased memory recall performance (Bhandari, 2019). The environment was used to teach people data compliance policies, and participants were able to recall much of the policies in comparison to a group that learned the information from paper, especially in the long term. The study also showed high compliance to use the method, much like many other studies, supporting the idea that these VR MoL environments are quite encouraging compared to traditional methods of learning (Bhandari, 2019).

Finally, a study (Peeters & Segundo-Ortin, 2019) that reviewed various other VR MoL studies as well as more traditional MoL, investigated why the MoL is so effective, and how they might come up with design advice for future VR MoL experiments where high memory recall performance is the goal. The authors suggest increasing immersion as much as possible, lighting up potential areas of interest or using unique landmarks for placing things to be remembered in the palace, making participants use physical body movements to interact and place memorized things as well as move about, and make it so that participants can choose or even better, create imagery for items to be remembered when tasked with memorizing them. They also express interest in future studies of animating things to be remembered through moving objects or videos.

2.7 VR Immersion

Examining past research in VR MoL experiments, there is a significant number of researchers encouraging increased immersion for better recall of information (Huttner, Robbert, & Robra-Bissantz, 2019; Krokos et al., 2019; Huttner & Robra-Bissantz, 2017). Further review was done on two papers that investigated how to increase immersion in simulated environments (Sanchez-Vives & Slater, 2005; Kong et al., 2017). Both studies expressed through experimental results and review of other research that virtual body representation is important. Not being able to see one's self in a simulated environment can be strange to people, and it is recommended that a virtual representation be synced with the movements of a participant (Sanchez-Vives & Slater, 2005; Kong et al., 2017).

When able to see one's own hands or legs moving where they expect them to, and at the times they are expected to move, people feel a higher sense of ownership and agency over their virtual bodies (Kong et al., 2017). This leads to people feeling more like they are truly in the environment as if it were real, and theoretically this should lead to better memory recall in a VR MoL scenario.

Other papers, such as Sanchez-Vives & Slater (2005), supported 3D sound as an important factor to immersion. Haptic feedback when touching virtual surfaces, realistic walking, meaningful movements of the actual body of a participant, and inducing any intense emotion like fear are also mentioned by the authors as ways to improve upon making the participant feel more like they are present in a virtual environment.

Chapter 3

Methodology

3.1 Design of the Software (VR) System

In order to conduct the VR MoL Phase of the experiment in this thesis, a software system was developed to simulate the MoL memory palace in a VR environment using Unity 2019.2 and C#. The Oculus Rift S was used extensively for development, but the system supports most VR headset technology. Usage of controllers associated with the headsets has been integrated into the application using the Unity XR plugin management system. All things seen in the VR environment by participants were able to be viewed on a monitor running the Unity editor, where a researcher conducting the experiment can observe and record notes. KAT VR's KAT Loco ankle and waist sensor devices for realistic walking in the simulated environment were integrated into the software using the open-source Unity SDK available from the developers of the product.

3.1.1 Memory Palace Structure Design

The simulated environment was designed according to the floor plan seen in the screenshot of the virtual memory palace shown in Figure 3-1, in order to look similar to an apartment. An apartment was chosen for the place the palace should be modeled after because familiarity with the structure of an environment has been shown to produce slightly better memory recall results as opposed to other memory palace structure designs (Caplan et al., 2019). Also, multiple other studies have made use of palaces designed based on the structure of an apartment (Caplan et al., 2019; Huttner, Robbert, & Robra-Bissantz, 2019; Huttner & Robra-Bissantz, 2017; Huttner et al., 2018; Huttner, Qian, & Robra-Bissantz, 2019; Legge et al., 2012; Jund et al., 2016). The 3D model of the apartment used in this thesis' experiment was visually designed and generated by Tyson Moll. The furniture models populating the apartment were free use license models used for purely academic purposes, made by other creators. The environment was designed to be basic in detail and non-interactive (one could not open the fridge or close the barbecue, for example) in order to prevent the environment from distracting participants from their main task of memorization in the experiment.

As shown in Figure 3-1, the memory palace contains a kitchen, dining area, office, bathroom, two bedrooms, a storage room, a living area, a recreation room, and a balcony. Some screenshots of various rooms in the memory palace can be seen in Figures 3-2, 3-3, 3-4, 3-5, and 3-6. When a participant's avatar was spawned into the environment, participants began at the location labeled 'Start Point' on Figure 3-1. While an apartment's general structure is familiar, it has also been said traditionally that the MoL should include usage of non-repetitive, distinct environments for more effective use of the mnemonic technique (Yates, 1999). The apartment design was loosely inspired by multiple high-end condo apartment designs found online to try and create something that looked distinct and unique while not taking away from the idea of having a familiar, building-like structure appearance (Caplan et al., 2019).

3.1.2 Word Selection

Words used for the pre-testing and post-testing phases of the experiment were chosen based on high imageability or concreteness. The words were randomly selected from a total pool of words proposed to be of high imageability by Madan et al. (2010). This means that the words were easy for one to imagine or visualize in their head compared to other words. In a specific study using this same word pool, high imageability words

Figure 3-1: Virtual Memory Palace Apartment Design.

Figure 3-2: Bedroom 1 of the Virtual Memory Palace Apartment.

Figure 3-3: Balcony of the Virtual Memory Palace Apartment.

Figure 3-4: Recreation Room of the Virtual Memory Palace Apartment.

Figure 3-5: Kitchen, Dining, and Living Areas of the Virtual Memory Palace Apartment.

Figure 3-6: Office of the Virtual Memory Palace Apartment.

were shown to lead to better memory recall performance in a virtual memory palace MoL scenario, as opposed to words of low imageability (Legge et al., 2012).

All high imageability words in the pre-existing pool of words from Madan et al. (2010) were equally likely of being selected for either the pre-test or post-test, except for two words that were excluded because they did not seem appropriate to the North American participant pool. These words were “Brandy” and “Chap.” The word lists used in the experiment were 30 words in length and can be found in Tables 3.1 and 3.2.

Table 3.1: Randomly selected word list for the first week's experiment Pre-Test Phase.

Bolt	Roast	Ankle
Crowd	Burial	Riot
Drive	Stable	Beard
Twin	Toilet	Tank
Cigar	Scarf	Sponge
Basket	Lace	Tail
Limp	Flame	Rubber
Veil	Bill	Meal
Stain	Card	Crest
Beam	Bone	Devil

Due to a limited number of participants available, it was also decided that participants would be asked if they were willing to return for a second run-through of the experiment at least one week after their previous attempt at using the method of loci in VR. This experiment was run with word lists of 30 words in length as well,

Table 3.2: Randomly selected word list for the first week's experiment Post-Test Phase.

Canal	Feast	Gate
Helmet	Rose	Hammer
Chapel	Cave	Limb
Bishop	Troops	Museum
Cart	Dwarf	Barrel
Onion	Flock	Blouse
Drum	Deer	Infant
Salt	Tongue	Button
Autumn	Disc	Wound
Essay	Cherry	Ladies

Table 3.3: Randomly selected word list for the second week's experiment Pre-Test Phase.

Stake	Flesh	Bible
Dwarf	Spain	Wound
Motor	Italy	Queen
Breast	Drum	Armour
Plate	Lung	Tomb
Bishop	Wreck	Badge
Stool	Dummy	Cabin
Bike	Gift	Crust
Salt	Hunter	Prince
Bucket	Skull	Deer

and these new word lists generated from the same overall pool of words can be seen in Tables 3.3 and 3.4. The word lists were generated for this in a way that would guarantee that none of the words from the first week's pre-test would be in the second week's pre-test, and likewise for the post-test word lists.

The words used in the post-tests had three pictures pre-selected for them each. This was so that the participant in the virtual environment could choose one of these three related pictures to change how the word to be remembered was displayed in the memory palace during usage of the MoL mnemonic technique. Some examples of these images can be seen in Figure 3-7.

Table 3.4: Randomly selected word list for the second week's experiment Post-Test Phase.

Guinea	Lens	Rifle
Rope	Rocket	Smoke
Parcel	Dish	Steel
Angle	Squash	Slope
Lock	Deck	Stain
Pole	Aisle	Flame
Linen	Isle	Cigar
Eleven	Bullet	Crest
Twist	Stove	Crowd
Sketch	Fuel	Veil

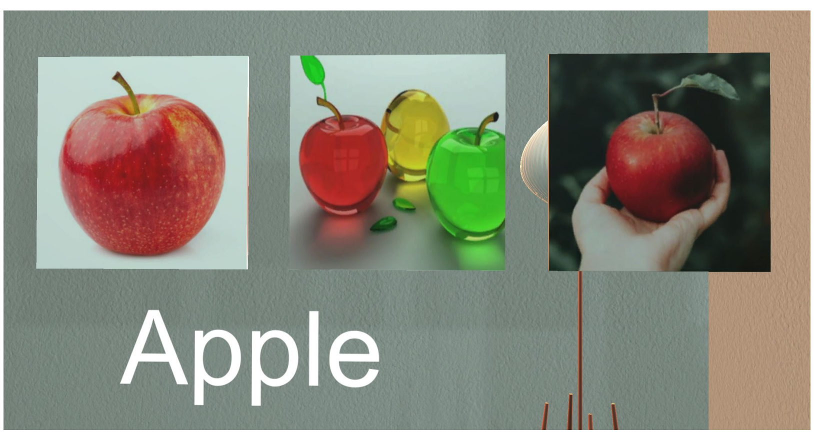


Figure 3-7: *ImageSelector* with three *ImageSelectorComponent* options for the word *apple*.

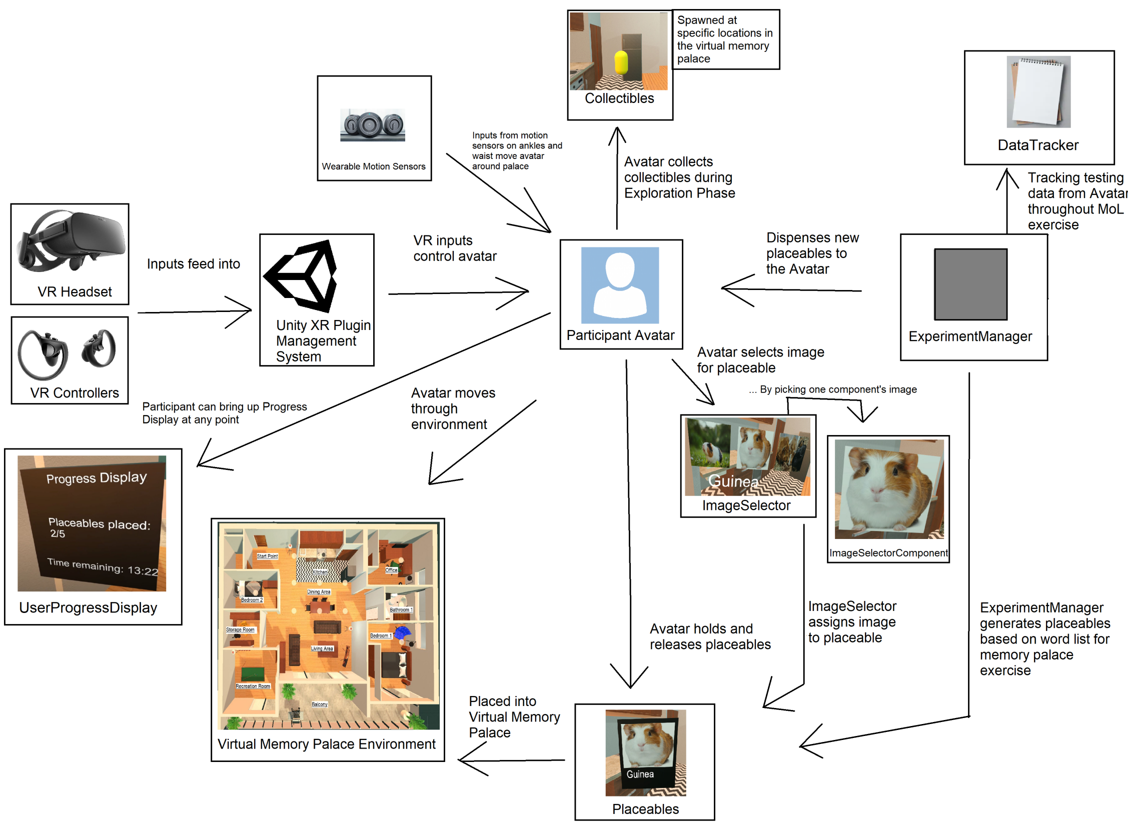


Figure 3-8: Software System Design Diagram.

3.1.3 Software System Design

As shown in Figure 3-8, the system makes use of the Unity XR plugins to allow support for various headsets such as the Oculus Rift S, and this plugin management system sends various input data from controllers and headsets to be accessible throughout Unity. A Participant Avatar exists that was made up of only two gloved hands, representing the participant and controlled entirely by the inputs from the VR headset, controllers, and the worn ankle and waist sensors used for realistic walking. Participants can see their avatar hands and use them for all of their interactions with the virtual world. While it was originally planned that the feet of the avatar would be shown too, it was found to be difficult, if not impossible, to implement using the data from the KAT VR Loco sensors.

Spawning of participant avatars to begin the experiment were controlled with an *ExperimentManager* object. This system keeps track of time limits in the Participant Training Phase and the VR MoL Phase. The *ExperimentManager* also tracks progress of collecting *collectible* objects in the area during the Participant Training Phase (the number of collectibles remaining to be collected), and it tracks the progress of placed objects to be remembered in the VR MoL Phase (the number of objects to be remembered remaining to be placed in the palace). This time and progress information was visible to participants through pop-up dismissible displays known as *UserProgressDisplays* that could be presented and dismissed with a simple button press on a held controller in one hand. A *UserProgressDisplay* can be seen in Figure 3-9. Using something known as the *DataTracker*, the time required by participants to place each object, the locations of the objects placed, which images for each object were selected, the times the *collectibles* were collected, and the order the *Collectibles* were collected, was all recorded and stored in text files.

Various points in the palace environment were chosen for collectible floating objects (*Collectibles*) to be spawned in (*CollectibleSpawnPoints*). These objects were destroyed when a participant touched them with either of their hands. When destroyed, they reported to the *ExperimentManager* that they had been collected.

Figure 3-9: A *UserProgressDisplay* showing timing and progress information to a participant.

The memory palace itself was made of simple 3D models with no functionality except for preventing the participant from moving through them by using 3D colliders. Participant avatars seem to walk on the spot and not move through the virtual environment if they try to move through a virtual object.

An *ImageSelector* object takes care of image selection prior to placing each item to be remembered. Depending on which specific word was being placed next, three relevant images were presented before the participant, and using their hand, they can reach out and touch one of the pictures to select it for the item to be placed. *ImageSelectors* spawned based on wherever participants were facing, with some distance in front of them so that each *ImageSelectorComponent* could be seen clearly. Each component of an *ImageSelector* contains a single image that was one of the three choices for a given word to be remembered. An *ImageSelector* can be seen in Figure 3-7.

Objects to be remembered that were to be placed around the palace were known as *Placeables*. An example of a *Placeable* can be seen in Figure 3-10. The items were shown to participants in the order that they were in the list to be memorized, to try and enforce an order for the purpose of the MoL's path-based memorization technique. It was thought that participants could form a path from the first item placed to the last. After the image selection process was complete for an item to be remembered, a chosen image was placed on a blank black background of a flat object with the word associated with it and a new *Placeable* object floated in front of the participant until interacted with. The flat slate object was to be held physically by the user and was able to be manipulated by the participant completely using handheld VR controllers such as the Oculus touch controllers. By gripping on a controller, *Placeables* were able to be picked up, and naturally loosening that grip leads to dropping or placing a *Placeable*. Pressing and releasing the grip trigger button on the controllers to do this was a natural motion just like picking up or dropping a real object, and so it lends more immersion to the simulation. If at any point a *Placeable* was dropped, thrown, or placed in some accidental position, as long as the placement has not been

Figure 3-10: A *Placeable* object that represents a word on a word list to be remembered by a participant.

confirmed, participants can use a certain button press on their controllers to bring the *Placeable* back to be floating in front of them once more, like when it spawned.

Once placed where the participant wishes it to be, a button on the controller in a user's hand was used to confirm the placement. The *Placeable* then plays a chiming sound in a 3D fashion coming from the direction where it was placed in the virtual environment relative to the participant's position. Once placement was confirmed, the *Placeable* cannot be moved, and a new image selection process for the next word in the word list to memorize begins as managed by the *ExperimentManager* and a newly spawned *ImageSelector*. Upon completion of the image selection process, a new *Placeable* spawns like the previous, in front of the user to be grabbed and placed. The process repeated and continued until the list of items to be remembered was exhausted.

3.2 Main Experiment

3.2.1 Participants

Eleven volunteers were recruited to participate in the experiment. While participants were originally to be sampled and recruited from the Sheridan College population in Oakville, Ontario, Canada, due to the restrictions brought with the onset of COVID-19, convenience sampling was opted for, and instead participants were only those that could be allowed to be in close proximity of either the author or the thesis supervisor. Each participant was told that the experiment would involve using a virtual reality system in combination with an ancient memorization technique to memorize large amounts of information, and that their results would be compared against their typical studying strategies. Due to the convenience sampling restrictions leading to a small group of participants, participants were asked to do the experiment for a second time as well as the first, if possible, after it had been at least a week since their first attempt.

3.2.2 Materials

For the purpose of this thesis, an experiment was conducted with human participants in a single group, making use of the method of loci in a virtual environment with a head-mounted display. The HMD used was the Oculus Rift S, and the simulated memory palace environment was developed using Unity with C#, on a Windows 10 desktop computer. Participants made use of the two touch controllers that accompany the Oculus Rift S device for more realistic use of their hands and arms, and they also used KAT VR's KAT Loco sensors to simulate realistic walking. The sensor devices have an open-source Unity SDK for integrating realistic movement into software for added immersion. Lastly, the cable coming out of the HMD was hung from the ceiling to be out of the way of participants using a product called Freestep VR Cable Management System, from the company Hyperkin.

3.2.3 Procedure

Pre-Test

Participants first completed a spatial cognitive ability test consisting of 5 training mental rotation tasks and 10 testing mental rotation tasks provided on a computer using a Python application (*Mental rotation task*, 2018). (This Python application was run using PsyToolkit (Stoet, 2010, 2017)) The percentage of correct answers and the average time taken per mental rotation task for the participant was recorded for the 10 testing mental rotation tasks. This testing was done to collect information that might help explain differences in participant performance during use of the MoL technique. In another study, it was suggested by results that those who complete mental rotation tasks better also tend to have better recall (Vindenes et al., 2018), so the spatial cognitive ability of participants was deemed important to keep track of.

After this test, 30 words were shown to each participant consisting of high imageability words randomly selected from a list provided in Madan et al. (2010). The number of 40 words was suggested in Ross & Lawrence (1968) originally and used also in Huttner, Robbert, & Robra-Bissantz (2019) as a way to have enough for the participant to memorize as to truly see the benefits of the MoL. High imageability (how easily the words can be imagined in one's mind) words have been suggested by multiple studies to be highly effective for the use of the MoL (Kroneisen & Makerud, 2017; Legge et al., 2012), as they result in memories that were easier to retain than when trying to memorize words with low imageability. This word list was presented to participants on paper and each was given 15 minutes to memorize as many words as they possibly could, in order if possible, using any memory strategy they wished.

Either when time was up or they felt as ready as they could be, participants were moved to a separate testing area where they were told to try writing down each of the 30 words they were told to memorize, as closely to the original ordering as possible. Participants were moved to a separate area for testing so as to avoid any bias of being tested in the same area as one learns in, as it has been shown that information can be more easily recalled in the location it was learned in Godden & Baddeley

(1975). The written recall test had a maximum time limit of 5 minutes if required by the participant taking the test, and afterwards, participants were given no feedback on their performance that might affect how they think in the second written test described later.

Participant Training Phase in the VR Environment

As the MoL is known to be a complex mnemonic technique (Yates, 1999), it was important to allow participants to become familiar with the technique and the memory palace they plan to use for it before having them make an attempt at using it. In order to do this, each participant was introduced to what the MoL entailed using an explanation of the technique from Huttner & Robra-Bissantz (2017), paraphrased and used by Legge et al. (2012), and originally taken from Yates (1999). This explanation is as follows from Huttner & Robra-Bissantz (2017); Yates (1999):

"In this method, memory is established from places and images. If we wish to remember an object, we must first imagine that object as an image, and then place it in a location. If we wish to remember a list of objects, then we must make a path out the many locations. The easiest way would be to imagine a familiar environment and place the imagined objects inside it. Then, you can pick up the objects as you imagine navigating the environment, thereby remembering the object list in order."

After being told about the technique, participants were allowed to ask questions to clarify anything they were unsure of regarding the technique. Through encouraging participants to use the MoL technique with direct instruction and thorough explanation, it is hoped to increase compliance in participants, which has been shown to be a problem in MoL experiments with particularly older people (Verhaeghen & Marcoen, 1996). When it was certain that they were aware of the MoL, they were introduced to the virtual reality equipment prepared to simulate a virtual memory palace.

Participants were given 10 minutes to learn how to use the virtual reality system that was designed, so that they were aware of how to grab and place objects, as well as how to walk around in the virtual environment and use the controls available to them. As they were spawned within the memory palace they were going to be using, some of this time also was allotted as time for them to explore each of the available rooms and areas to become more familiar with the space. Participants were allowed to take more than 10 minutes for this part of the experiment if they felt they needed it.

Familiarity with the memory palace to be used in the MoL has been shown to be a significant factor for better performance in memory recall in several studies (Reggente et al., 2019; Caplan et al., 2019; Jund et al., 2016). It is important to note that participants in the experiment conducted were given very little time to train and prepare for using this technique in comparison to other studies where multiple weeks or a few days were provided for getting familiar with the MoL (Huttner, Robbert, & Robra-Bissantz, 2019; Bhandari, 2019; Liu et al., 2019; Huttner et al., 2018; Huttner & Robra-Bissantz, 2017). If the experiment in this thesis produced significant memory performance increases in participants between the pre-test and post-test, we hypothesized that if people were given more time with the same environment, their recall performance would show even further improvements, especially in long-term memory of the information to be memorized.

As purposeful navigation has been suggested to be more memorable than simply wandering the memory palace without a specific aim (Reggente et al., 2019; Bhandari, 2019), 15 floating collectible items were placed around the palace for participants to find and collect by touching them. The locations of these collectibles throughout the palace can be seen in 3-11 With the items being scattered throughout the palace, collecting them allowed participants to explore every room thoroughly. Collectibles were used for exploration of memory palaces in other studies that were found as well (Reggente et al., 2019; Bhandari, 2019), and they follow the principle of trailblazing (Darken & Sibert, 1993; Bhandari, 2019), by creating a specific path through the memory palace in which a given participant does not need to explore any given area twice.

During this phase of the experiment, the remaining time available and remaining collectibles to find were displayed for participants on a pop-up menu that they could

Figure 3-11: Positions of *Collectibles* throughout the memory palace.

show and dismiss with a simple button press. The phase ended when either time ran out or the participant felt comfortable with the memory palace and the controls of the virtual reality environment.

When exploration of the environment was complete, a very short version of the VR MoL Phase of the experiment with only 5 words, none of which were on the lists of words to actually memorize, was started for the participant. This portion of the training phase was meant to introduce participants to the process of selecting images and manipulating placeable items that represented the words to be memorized. This would theoretically ensure that during the VR MoL Phase, the participant would not be wasting any of their time trying to figure out how to use the interface of the VR MoL environment. The words used for this short training phase were the same both weeks, and they were apple, orange, jungle, monkey, and speaker.

VR MoL Phase

Similar to the way the pre-test memorization phase was conducted, participants were given 15 minutes to memorize another set of 30 words randomly chosen from the same pool of high imageability words, without choosing any of the words used in the pre-test memorization phase. However, unlike in the pre-test memorization phase, participants made use of the MoL in the virtual environment they had explored in order to memorize the new list of words they were given.

Words were given to them one at a time to present them in a specific order like in the pre-test, to encourage memorizing how they were placed in the MoL as a path through the structure from the first word placed to the last word placed. Keeping track of a path when using the MoL to place and recall memories is integral to the traditional technique, allowing people to theoretically memorize items in their original order with more accuracy than with other memorization strategies (Yates, 1999).

When a word was presented to a participant to memorize, the text was shown in front of them with three different images above it that matched the word. The participant was able to use one hand to select an image they felt they would like to use to memorize the word, by simply moving their hand into the image and pressing no buttons. The other two images disappeared, and the chosen image was attached to a newly spawned object that looked like a floating black slate. Under the image, the new object also had the word in question to memorize, written on it. The participant could then reach out and grab the black slate object known as a *Placeable*, and then find a place that feels memorable in the memory palace to place the item. Words were randomly preselected in advance to the experiment in order to prepare the images for each word to be memorized.

The motivation behind allowing participants to choose an image they feel matches with each given word is to allow personalization of items to be remembered, allowing them to be displayed how they wish. Studies have shown that personalization of how memorized items were displayed could lead to improved recall (Bhandari, 2019; Peeters & Segundo-Ortin, 2019), being something often done by memory champions but rarely if ever done before in virtual MoL research studies.

When a participant placed a given item, it played a 3D sound from the location it was placed in, sounding somewhat like the ding of a bell. Originally it was considered that sounds could be chosen relevant to each item to be remembered, but due to time constraints and the large number of items to be memorized, this was not done. Sounds were played to increase sensory involvement in the task of placement. It has been shown that providing more audio, body movements, tactile feedback, and other sensory information to the user can increase immersion and presence in a simulated environment (Sanchez-Vives & Slater, 2005; Kong et al., 2017), and as shown in other studies, further immersion leads to better memory recall (Huttner, Robbert, & Robra-Bissantz, 2019; Krokos et al., 2019; Huttner & Robra-Bissantz, 2017).

All throughout the virtual simulation, participants saw a simulated representation of their hands when they looked at themselves, because certain research has shown this will further increase immersion in the environment (Sanchez-Vives & Slater, 2005), and thus, increase memory recall accuracy (Huttner, Robbert, & Robra-Bissantz, 2019; Krokos et al., 2019; Huttner & Robra-Bissantz, 2017). Having the avatar's feet be visible was also considered for added immersion, but it proved to be quite difficult to implement with the ankle sensors on-hand. Making the item glow visually for a moment was another consideration, but this ended up being too time-consuming to implement.

When all items had been placed and the participants felt comfortable with remembering what had been placed, or the time to complete the memorization process had expired, participants were instructed to leave the simulated environment.

Post-Test

Finally, the participants were moved to the same testing area they were tested in before, and there, were asked to try to remember all 30 of the words they tried to study in the memory palace, in order if possible. Like the pre-test, the post-test lasted a maximum of 5 minutes, and participants did not know their results afterwards. When finished with the post-test, participants were given a questionnaire. The questionnaire consisted of the following questions (See Table: 3.5). These questions were chosen due to their similarity to those posed to participants in other similar studies (Legge et al., 2012; Huttner & Robra-Bissantz, 2017; Caplan et al., 2019; Reggente et al., 2019).

3.3 Pilot Study

In order to ensure that the proposed experiment procedure had been defined correctly, a pilot study was conducted. The author of this thesis tested the procedure and virtual memory palace system to provide insights into refining the actual experiment procedure in order to be more effective for gathering the desired performance results from participants. Important reasons for conducting this pilot study are shown in the following:

- For determining how much time is truly needed to complete each section of the experiment, to be able to find an appropriate set of time limits to enforce throughout the procedure.

Table 3.5: Questionnaire Contents

1. What strategy did you use during the first memory recall test to memorize the words shown to you before entering virtual reality?
2. How much experience did you have in virtual reality prior to this experiment? (Rating your experience from 1 (not at all experienced) to 5 (very experienced).)
3. Did you use the method of loci (MoL) in the second memorization test, after using virtual reality, as instructed?
4. How confident were you with your answers in the first recall test (before VR)? (Rate your confidence from 1 (not confident at all) to 5 (very confident).)
5. How confident were you with your answers in the final recall test (after VR)? (Rate your confidence from 1 (not confident at all) to 5 (very confident).)
6. How immersive did you find this environment? Or, how much did you feel you were *in* the virtual world? (Rate from 1 (not immersed) to 5 (very immersed).)
7. Before the experiment, did you have any knowledge of what the method of loci (MoL) was?
8. If you had the chance to use a system like this to memorize things in a real-life situation, would you? Why, or why not?

- To determine if the virtual memory palace environment is too large or small for participants to realistically traverse and complete the task given to them effectively.
- To determine if the architectural structure of the environment should be changed to create new pathways where there are none, or to remove pathways through the memory palace that existed before.
- To make sure that the size of the word lists in the pre-test and post-test phases of the procedure (originally 40 words) are of an appropriate size for the tasks given to participants.
- To ensure that the process of getting a new word, selecting an image for it, and placing its representative object in the memory palace, is streamlined and clear enough to allow participants to complete their tasks reasonably quickly without getting distracted from their goal: Memorization of the items.

3.3.1 Participants

The author of this thesis alone participated in the pilot study.

3.3.2 Procedure

The procedure was identical to the main experiment's planned procedure except that participants were given 10 minutes to study word lists in the pre-test and post-test and the word lists consisted of 40 words.

Words used in the pre-test of the pilot experiment can be found in Table 3.6, while words used in the post-test of the pilot experiment can be found in Table 3.7.

3.4 Internal Validity

To ensure that the experiment in this thesis could measure what it was intended to effectively, various measures were taken:

Table 3.6: Randomly selected word list for pilot experiment Pre-Test Phase.

Bolt	Armour	Beam	Lace
Crowd	Tomb	Bible	Flame
Rubber	Sponge	Roast	Bill
Meal	Tail	Card	Cigar
Crest	Burial	Bone	Basket
Devil	Badge	Ankle	Limp
Drive	Stable	Queen	Veil
Twin	Toilet	Riot	Stain
Hunter	Cabin	Beard	Crust
Skull	Scarf	Tank	Prince

Table 3.7: Randomly selected word list for the pilot experiment Post-Test Phase.

Cart	Aisle	Bullet	Rifle
Onion	Troops	Bishop	Ladies
Drum	Dwarf	Stove	Smoke
Salt	Isle	Museum	Disc
Autumn	Flock	Barrel	Steel
Essay	Deer	Blouse	Cherry
Deck	Tongue	Infant	Gate
Feast	Canal	Fuel	Slope
Rose	Helmet	Button	Hammer
Cave	Chapel	Wound	Limb

- Experimental data was recorded electronically by automated scripts in all cases except for transferring the word lists written on paper by participants onto a computer. This was done to ensure the least amount of human error when recording information from the experiment.

- Participants were given as much time as they required to get comfortable with the VR environment, movement using the motion sensors, and making use of the various controls available to them in the simulated memory palace. This was done to reduce any bias towards participants with more VR experience being able to more quickly get comfortable with the environment. They were given ample time to explore the virtual apartment that is the memory palace. All participants only start the VR MoL phase of the experiment when they were fully comfortable and ready to do so.

- Participants were also instructed to complete a placing of items process with five items not from the list to be memorized, before doing the VR MoL phase of the experiment. This short training process allows participants to learn and become comfortable with what they need to do in the VR MoL phase before it begins, and therefore tries to reduce bias towards those that learn the VR environment's interface faster than others.

- A pilot experiment was conducted before the main experiment to try and make the main experiment's procedure more effective. The time limits for studying word lists were increased by 5 minutes to take into account participants that might be slower at moving around in the virtual environment. Also, the word list was reduced to 30 words rather than 40, due to the pilot study presenting results that suggested it would take approximately 20 minutes to place 40 items. Twenty minutes seemed like too long a time for continuous VR activity for those trying out VR for the first time or having a low amount of experience, so the word list was reduced to save time and hopefully reduce possible nausea in less experienced participants. By making these changes it is believed that bias has been reduced in the results related to participants getting nausea, tired, or bored, over the course of a longer experiment.

- The experiments were run using a script on paper that lists a series of steps for the one running the experiment to follow. This was meant to ensure that the experimental process was as uniform as possible between participants. The script used can be seen in Appendix 6.4.

3.5 External Validity

The results of this thesis can be generalized to multiple domains in which a VR-based MoL technique could be useful to memorize non-spatial information for a given purpose. Other studies such as Huttner et al. (2018); Huttner, Robbert, & Robra-Bissantz (2019); Huttner, Qian, & Robra-Bissantz (2019), have discussed the potential of an effective VR-based MoL technique before. Some example potential uses of this system could be:

- In colleges, universities, and other educational institutions, students often need to memorize large amounts of information to properly learn the subjects they are being taught. Even professors could use a technique like the one presented in this research to help them memorize their own lesson materials.

- People who have lost some of their memorization abilities, either through aging or some other reason, could make great use of a technique like this to maintain the strength of their memorization, especially in a long-term capacity. The MoL has been suggested to be quite effective for long-term memory (Huttner & Robra-Bissantz, 2017; Optale et al., 2010). This technique could also help those with poor memory get back memorization strength they used to have, or even improve their memorization abilities more than ever before.

- A technique like this could also help people remember positive memories during depressing times, as suggested in Dalgleish et al. (2013).

- In a way, a powerful, easy to learn memorization technique that removes the original complexities of the MoL like requiring extensive training, is a technique that could be useful to just about anyone who does not already use highly effective memorization techniques in their daily lives.

3.6 Analysis

The analysis in the research fell under quantitative and qualitative analysis. For quantitative analysis, strict and lenient scoring was calculated to evaluate the memory recall performance of participants in both pre-test and post-test phases of the experiment. Two t-tests were performed to compare pre-test and post-test scores for both lenient and strict scoring. Standard descriptive statistics were also calculated and the distribution of test scores were presented. Finally, for qualitative analysis, observations from the experiment were described and a questionnaire's results were both analyzed and discussed.

3.6.1 Quantitative Analysis

strict and lenient scoring

As done with multiple other similar studies (Mccabe, 2015; Huttner, Qian, & Robra-Bissantz, 2019; Huttner, Robbert, & Robra-Bissantz, 2019; Liu et al., 2019; Huttner et al., 2018; Huttner & Robra-Bissantz, 2017), originally proposed and used by the study Legge et al. (2012), memory recall performance for the pre-test and post-test were calculated by determining lenient and strict scores of participants. The lenient score is a percentage of simply how many words the participant recalled correctly divided by the total number of words to remember. On the other hand, the strict score is calculated using the *levenshtein distance*, an algorithm for determining how many changes must be made to a list of recalled words to make the list identical to the original list to be remembered. The strict score is thus a measure of whether words were remembered in the correct order. A description of the algorithm and its usage to determine the strict score is described in Huttner, Robbert, & Robra-Bissantz (2019):

"This algorithm is used to calculate the minimum costs of transforming one sequence (e.g. a string or an array of terms) into an original one (Levenshtein, 1966). The algorithm includes three basic operations: replace, delete and insert. Every time the algorithm has to use one of them, a counter increments the costs of transformation by one. In the end, the minimum costs are returned. For instance, the original sequence is table, spoon, fork, apple, banana while the user's input was spoon, fork, apple, banana, table. In this case, the order is almost perfect except for the term table. The levenshtein distance then deletes table and adds it at the beginning of the sequence. Hence, two operations were performed (deletion and insertion) and the cost of transforming the sequence is two. The strict score was then computed using the following formula:

$$strict\_score = 1 - \frac{lev(u, o)}{max} \tag{3.1}$$

The function **lev(u,o)** returns the levenshtein costs of the user input sequence **u** and the original sequence **o**. The value **max** represents the maximum amount of operations that might be necessary to transform any given sequence of terms (worst case scenario, in this setting it is the maximum length of the original sequence) into the original one. Hence, regarding the example the strict score would be $1 - \frac{2}{5} = 0.6$. This way of computing the strict score ensures an objective measure of the subjects ability to recall the terms in order. Furthermore, an increasing recall performance results in an increasing strict score that ranges between 0 and 1 (Huttner, Robbert, & Robra-Bissantz, 2019)."

In order to calculate these scores, the levenshtein distance algorithm was translated into a Python script and both lenient and strict scores were calculated within that same script.

Table 3.8: Example Lenient Recall Scores t-test.

	Pre-Test	*Post-Test*
Mean	0.429	0.6175
Variance	0.061946316	0.050503947
Observations	20	20
Pooled Variance	0.056225132	
Hypothesized Mean Difference	0	
df	38	
t Stat	-2.513889097	
P(T<=t) one-tail	0.008148408	
t Critical one-tail	1.68595446	
P(T<=t) two-tail	0.016296816	
t Critical two-tail	2.024394164	

Table 3.9: Example Strict Recall Scores t-test.

	Pre-Test	*Post-Test*
Mean	0.283	0.4165
Variance	0.039653684	0.038560789
Observations	20	20
Pooled Variance	0.039107237	
Hypothesized Mean Difference	0	
df	38	
t Stat	-2.134777909	
P(T<=t) one-tail	0.019644384	
t Critical one-tail	1.68595446	
P(T<=t) two-tail	0.039288769	
t Critical two-tail	2.024394164	

Statistical Analysis: t-tests, standard descriptive statistics

t-tests were conducted using the pre-test and post-test groups of strict and lenient scores from participants to determine if a significant performance difference had been observed as a result of using the VR MoL environment (post-test) as opposed to being uninstructed on what mnemonic technique to use for recall (pre-test).

Tables 3.8 and 3.9 present hypothetical findings in t-tests for lenient and strict recall scores respectively. In both t-test results, one can see that there is a significant improvement in scores during the post-test phases of the experiment compared to the pre-test phases, since the two-tailed p value is less than 0.05.

Table 3.10: Example Standard Descriptive Statistics for Lenient Pre-Test Scores.

Mean	0.429
Standard Error	0.055653533
Median	0.385
Mode	0.23
Standard Deviation	0.248890168
Sample Variance	0.061946316
Kurtosis	-0.926621293
Skewness	0.484496275
Range	0.78
Minimum	0.11
Maximum	0.89
Sum	8.58
Count	20

Table 3.11: Example Standard Descriptive Statistics for Lenient Post-Test Scores.

Mean	0.6175
Standard Error	0.05025134
Median	0.56
Mode	#N/A
Standard Deviation	0.22473083
Sample Variance	0.05050395
Kurtosis	-1.4246268
Skewness	0.21092237
Range	0.69
Minimum	0.29
Maximum	0.98
Sum	12.35
Count	20

Various standard descriptive statistics are displayed about the lenient and strict scoring data for both pre-test and post-test conditions in the following four Tables: 3.10, 3.11, 3.12, and 3.13.

Through the boxplot Figures 3-12 and 3-13, one can see the distribution of test scores in both pre-test and post-test for lenient and strict scoring, displaying a clearly visible increase in test score from pre-test to post-test conditions in both cases.

3.6.2 Qualitative Analysis

The following types of qualitative analysis were also performed, namely,

Table 3.12: Example Standard Descriptive Statistics for Strict Pre-Test Scores.

Mean	0.283
Standard Error	0.04452734
Median	0.22
Mode	0.45
Standard Deviation	0.19913233
Sample Variance	0.03965368
Kurtosis	0.14683312
Skewness	0.92753632
Range	0.73
Minimum	0.02
Maximum	0.75
Sum	5.66
Count	20

Table 3.13: Example Standard Descriptive Statistics for Strict Post-Test Scores.

Mean	0.4165
Standard Error	0.043909446
Median	0.33
Mode	0.24
Standard Deviation	0.196369014
Sample Variance	0.038560789
Kurtosis	-0.385130994
Skewness	0.946781468
Range	0.64
Minimum	0.18
Maximum	0.82
Sum	8.33
Count	20

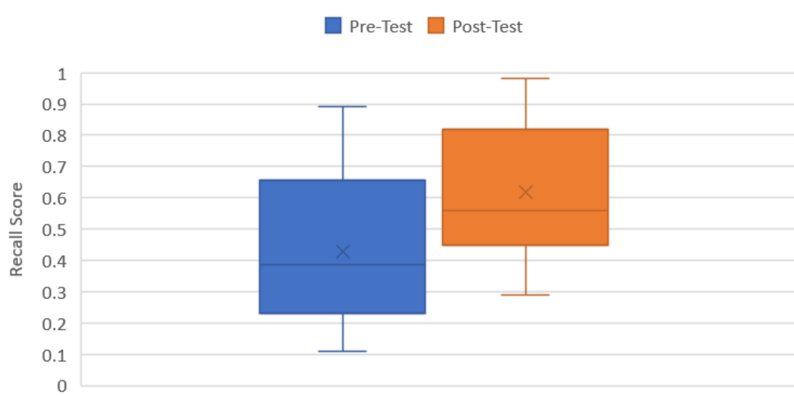


Figure 3-12: Example Lenient Recall Scores Boxplot.

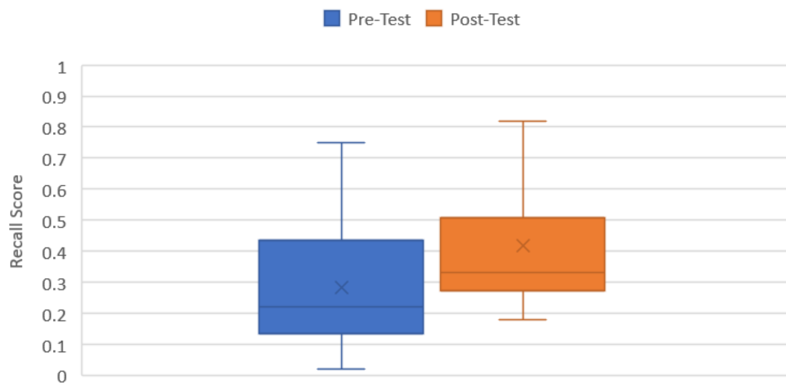


Figure 3-13: Example Strict Recall Scores Boxplot.

1. *Researcher Observations* (participants observed by research during the experiments): Common themes and trends that emerged from observing the participants as they performed the experiment were summarized and presented. These observations came from either viewing their progression on the display monitor showing their view within the simulation (using the Unity editor), or from watching their physical self move in the real world.

2. *Surveys*: By examining the results of the questionnaire presented in Table 3.5, observed themes and trends that emerged were summarized and discussed in detail. These observations could be about compliancy with the mnemonic technique (MoL), levels of experienced immersion by participants, how likely they would be to use the technique in their daily lives, how much prior knowledge of the technique affected the experiment results, etc. Questions in the questionnaire that are answered with a number between 1 and 5 will also have their results analyzed in a quantitative fashion.

Chapter 4

Findings (Analysis and Evaluation)

4.1 Pilot Study Findings

Based on the results of the pilot experiment, the main experiment's procedure was altered to be more effective. In the pilot experiment, there were 40 words to remember rather than 30, and 10 minutes to study word lists, rather than 15 minutes. The time was found to be far too short to accomplish the task in the VR environment, and the word list was deemed to be long enough that it might take so long that nausea may come to participants if they were trying VR for the first time or had not had much experience with it prior.

4.2 Main Experiment Findings

Data labeled with 'Week 1' are results were drawn from the first week of the experiment being run with participants, and each participant is represented by a name from P1 to P11 in order to keep their names anonymous. Data labeled with 'Week 2' represent how participants did when asked to do the experimental procedure once more at a later time. Not all participants could participate in the second week of experiments, so there are naturally more results for the first week.

Table 4.1: Week 1 Mental Rotation Task Results.

Participant	Percentage of correct mental rotation task answers (%)	Average time taken per mental rotation task (seconds)
P1	87	4614
P2	73	5363
P3	93	5465
P4	93	2226
P5	80	2248
P6	80	3686
P7	70	3257
P8	87	9077
P9	87	4222
P10	73	4404
P11	87	9354

Table 4.2: Week 2 Mental Rotation Task Results.

Participant	Percentage of correct mental rotation task answers (%)	Average time taken per mental rotation task (seconds)
P2	60	3111
P3	80	6700
P4	60	2068
P6	100	4426
P7	87	4248
P8	87	2849
P9	80	2262
P10	87	2976
P11	93	5782

Before each of the participants completed any other part of the experiment, they were asked to do ten mental rotation tasks to try and measure their spatial cognitive ability. The results of these tasks can be seen in Tables 4.1, and 4.2.

When participants collected each of the Collectibles objects in the memory palace, the order that they collected each of these items was recorded. Three of the paths taken by the participants can be seen in Figures 4-1, 4-2, and 4-3.

In Tables 4.3 and 4.4, one can see the resulting strict and lenient scores calculated for each participant during the first week of the experiment. These scores were calculated based on the lists of words written down by participants trying to recall the word lists they were told to memorize in the pre-test and post-test phases.

Table 4.3: Week 1 Lenient Recall Scores.

Scores	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Pre-test	87%	70%	67%	50%	90%	27%	73%	47%	100%	37%	40%
Post-test	93%	93%	93%	73%	93%	63%	97%	87%	100%	53%	67%

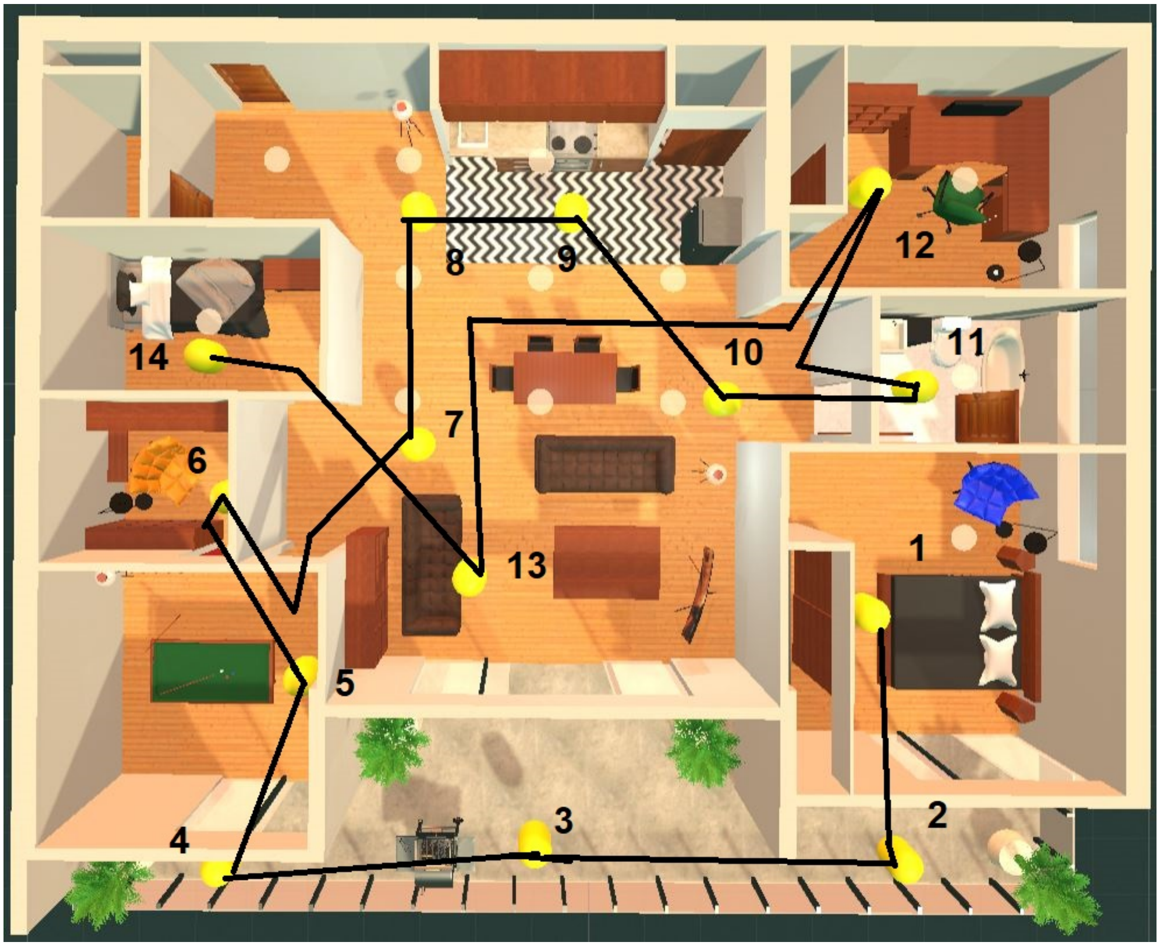


Figure 4-1: The path that participant P2 took to collect the Collectibles.

Table 4.4: Week 1 Strict Recall Scores.

Scores	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Pre-test	77%	30%	43%	13%	90%	3%	7%	47%	87%	33%	3%
Post-test	7%	13%	53%	13%	13%	3%	13%	17%	77%	43%	3%

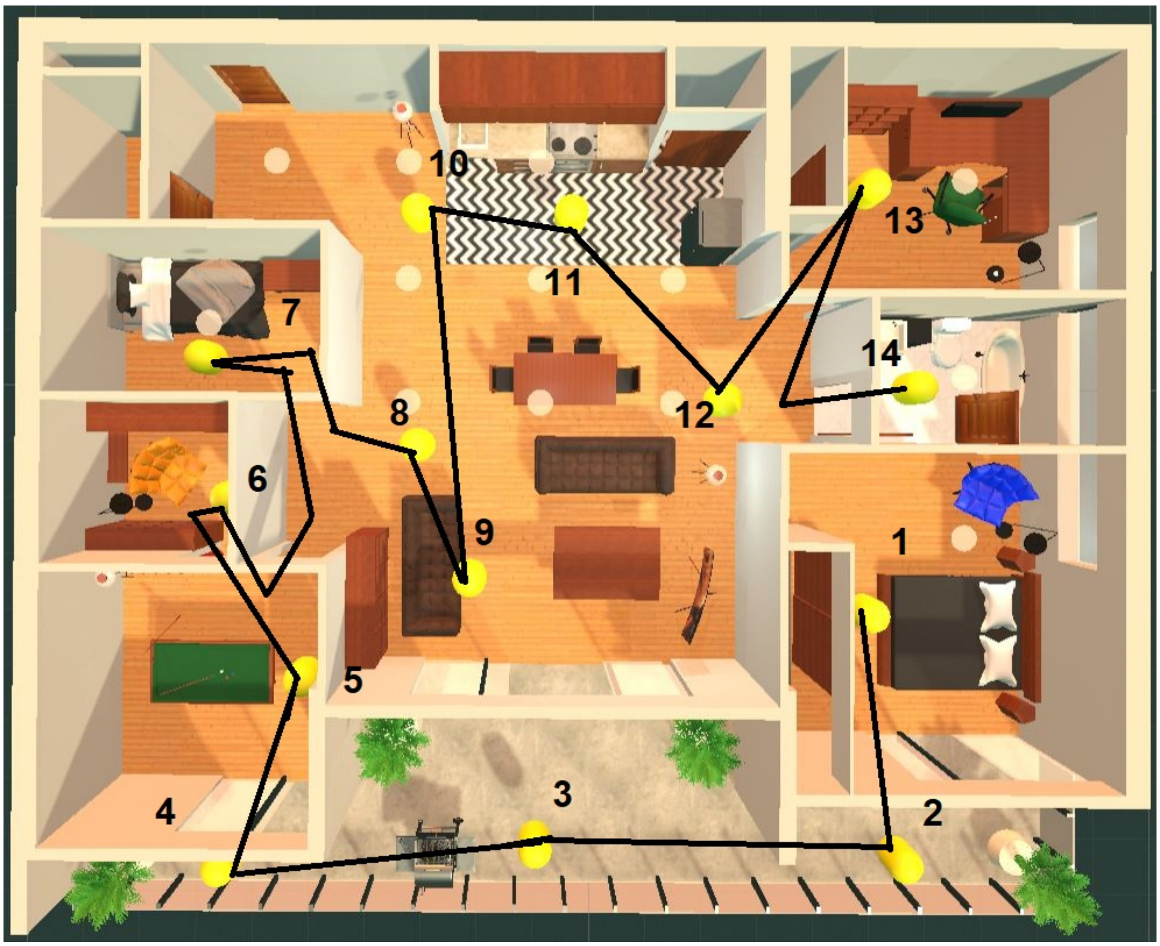


Figure 4-2: The path that participant P4 took to collect the Collectibles.

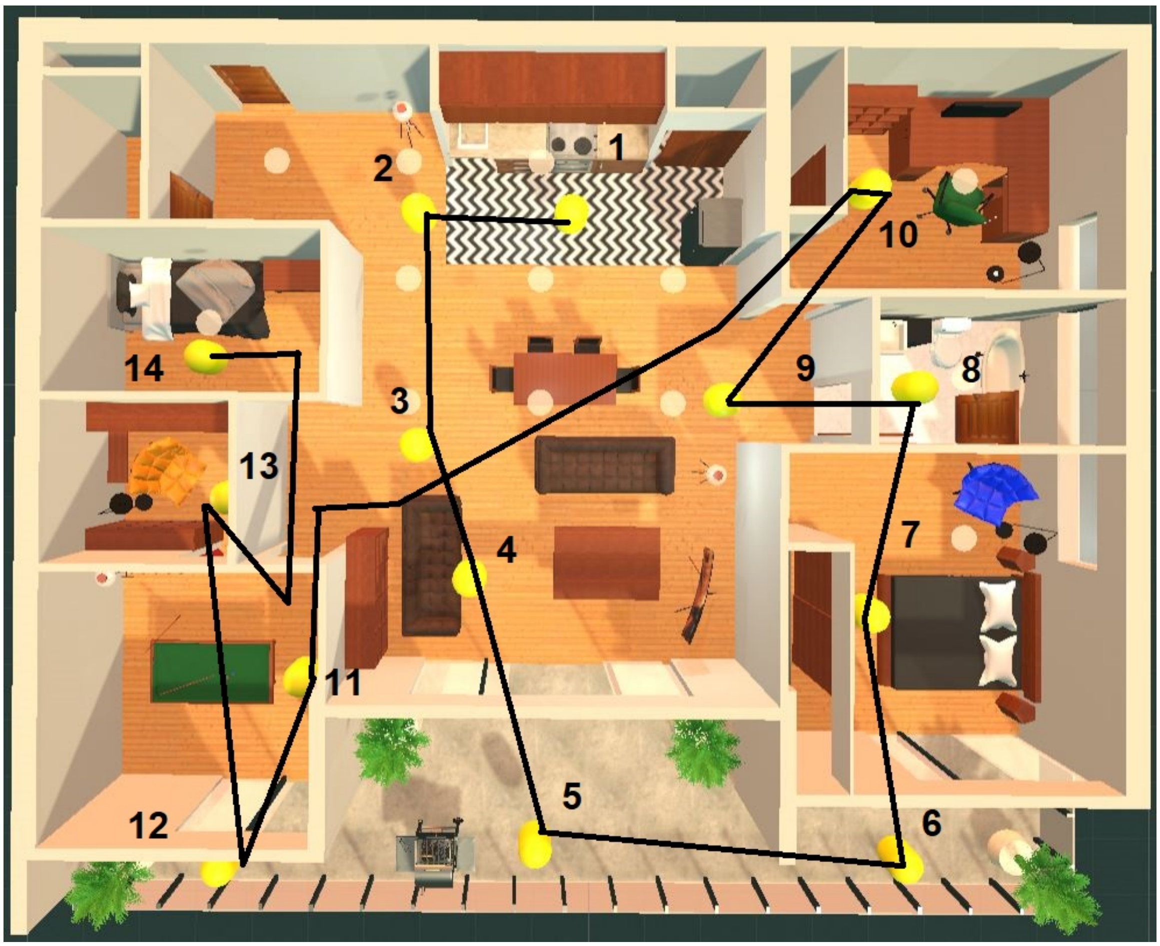


Figure 4-3: The path that participant P7 took to collect the Collectibles.

Table 4.5: Week 2 Lenient Recall Scores.

Scores	P2	P3	P4	P6	P7	P8	P9	P10	P11
Pre-test	100%	93%	57%	47%	77%	30%	87%	50%	30%
Post-test	97%	83%	90%	47%	97%	83%	97%	80%	97%

Table 4.6: Week 2 Strict Recall Scores.

Scores	P2	P3	P4	P6	P7	P8	P9	P10	P11
Pre-test	100%	73%	20%	13%	10%	30%	57%	50%	30%
Post-test	10%	60%	60%	13%	10%	7%	10%	7%	7%

The scores from the second week of the experiment can be seen in Tables 4.5 and 4.6.

The Tables 4.7 and 4.8 show what participants wrote down and how they compared to the actual word lists they were meant to recall, in the first week of the experiment. Participants who wrote synonyms of words in a word list to be remembered or made minor spelling mistakes were given the score for those words as if they had been written correctly, but otherwise any incorrect words were counted as if the participant had written nothing for that word. 'XXX' is used to show places on the word list where the participant did not write anything.

The written word lists in the pre-test and post-test of the second week of the experiment can be seen in Tables 4.9 and 4.10.

Tables 4.11 and 4.12 present findings in t-tests for lenient and strict recall scores respectively, in the first week of the experiment. t-tests done for the results from the second week of the experiment are presented in Tables 4.13 and 4.14. In the t-test results, one can see that, in both weeks of the experiment, there is a significant improvement in lenient scores during the post-test phases of the experiment compared to the pre-test phases, since the two-tailed p values were less than 0.05. However, there is insignificant change in the strict recall scores between pre-test and post-test, in both weeks of the experiment, as can be seen from the two-tailed p values being more than 0.05.

Various standard descriptive statistics from the first week of the experiment are displayed about the lenient and strict scoring data for both pre-test and post-test conditions in the following four Tables: 4.15, 4.16, 4.17, and 4.18. The same general

Table 4.7: Week 1 Pre-Test Participant Word Lists compared to Correct Word List.

	Participants										
Correct Pre-Test List	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Bolt	Bolt	Bolt	Bolt	Bolt	Bolt	Bolt	Riot	Bolt	Bolt	Bolt	Chapel
Crowd	Crowd	Crowd	Crowd	Cigar	Crowd	Scarf	Bolt	Crowd	Crowd	Crowd	Bishop
Drive	Drive	Drive	Drive	Twin	Drive	Veil	Flame	Drive	Drive	Drive	Troops
Twin	Twin	Twin	Twin	Drive	Twin	Bone	Crowd	Twin	Twin	Cigar	Dwarf
Cigar	Cigar	Cigar	Cigar	Cigar	Cigar	Burial	Devil	Cigar	Basket	Basket	Disc
Basket	Basket	Basket	Basket	Basket	Basket	XXX	Bone	Basket	Cigar	Limp	Hammer
Limp	Veil	Limp	Limp	Veil	Limp	Vein	Tail	Limp	Limp	Veil	Museum
Veil	Stain	Toilet	Veil	Lace	Veil	Card	Twin	Veil	Veil	Stain	Wound
Stain	Beam	Flame	Stain	Bone	Stain	XXX	Bill	Stain	Stain	Beam	Ladies
Beam	Roast	Lace	Roast	Bill	Beam	Trial	Drive	Beam	Beam	Roast	Flock
Roast	Burial	Card	Beam	Card	Roast	Rope	Tank	Roast	Roast	Burial	Deer
Burial	Stable	Bill	Scarf	Ankle	Burial	XXX	Rubber	Burial	Burial	XXX	Rose
Stable	Toilet	Bone	Lace	Tail	Stable	Soap	Beard	Stable	Stable	XXX	Essay
Toilet	Lace	Ankle	Bill	Meat	XXX	Train	Limp	Toilet	Toilet	XXX	Drum
Scarf	Flame	Roast	Card	Rubber	Scarf	XXX	Basket	XXX	Scarf	XXX	Onion
Lace	Bill	Burial	Bone	Flame	Lace	Rail	Lace	XXX	Lace	XXX	Infant
Flame	Card	Tail	Ankle	Read	Flame	Sail	Veil	XXX	Flame	XXX	Blouse
Bill	Bone	Rubber	Beard	Hammer	Bill	XXX	Scarf	XXX	Bill	XXX	Gate
Card	Ankle	Limp	Riot	XXX	Card	XXX	Burial	XXX	Card	XXX	Tongue
Bone	Riot	XXX	Tank	XXX	Bone	Bill	Card	XXX	Bone	XXX	Cave
Ankle	Beard	XXX	XXX	XXX	Ankle	XXX	Ankle	XXX	Ankle	XXX	XXX
Riot	Tank	XXX	XXX	XXX	Riot	Ankle	Meal	XXX	Riot	XXX	XXX
Beard	Tail	XXX	XXX	XXX	Beard	XXX	XXX	XXX	Beard	XXX	XXX
Tank	XXX	XXX	XXX	XXX	Tank	Trail	XXX	XXX	Tank	XXX	XXX
Sponge	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	Sponge	XXX	XXX
Tail	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	Tail	XXX	XXX
Rubber	XXX	XXX	XXX	XXX	Rubber	XXX	XXX	XXX	Rubber	XXX	XXX
Meal	Meal	XXX	XXX	XXX	Meal	Shoe	XXX	XXX	Meal	XXX	XXX
Crest	Crest	Crest	XXX	XXX	Crest	XXX	XXX	XXX	Devil	XXX	XXX
Devil	Devil	Devil	XXX	XXX	Devil	XXX	XXX	XXX	Crest	XXX	XXX

Table 4.8: Week 1 Post-Test Participant Word Lists compared to Correct Word List.

	Participants										
Correct Post-Test List	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Canal	Essay	Canal	Canal	Canal	Salt	Apple	Gate	Canal	Canal	Canal	Chapel
Helmet	Disk	Chapel	Helmet	Gate	Bishop	Rose	Helmet	Chapel	Helmet	Helmet	Bishop
Chapel	Drum	Bishop	Chapel	Chapel	Chapel	Deer	Troops	Helmet	Bishop	Bishop	Troops
Bishop	Cherry	Helmet	Bishop	Bishop	Essay	Blouse	Bishop	Bishop	Chapel	Cart	Dwarf
Cart	Salt	Feast	Cart	Canyon	Helmet	Wound	Cherries	Onion	Onion	Onion	Disc
Onion	Feast	Cherry	Onion	Salt	Disc	Ladies	Onions	Salt	Cart	Drum	Hammer
Drum	Ladies	Salt	Drums	Feast	Autumn	Infant	Salt	Rose	Drum	Salt	Museum
Salt	Autumn	Troops	Salt	Onion	Troops	Troops	Cherry	Cherry	Salt	Essay	Wound
Autumn	Flock	Dwarf	Essay	Cherry	Cart	Museum	Tongue	Ladies	Autumn	Feast	Ladies
Essay	Gate	Gate	Autumn	Tongue	Feast	Autumn	Cart	Blouse	Essay	Rose	Flock
Feast	Rose	Deer	Cave	Ladies	Dwarf	Priest	Essay	Tongue	Feast	Cave	Deer
Rose	Hammer	Flock	Troops	Autumn	Barrel	Church	Autumn	Infant	Cave	Troops	Rose
Cave	Blouse	Cart	Flock	Deer	Cave	Gate	Canal	Cart	Rose	Flock	Essay
Troops	Infant	Onion	Deer	Flock	Deer	Dwarf	Deer	Cave	Troops	Deer	Drum
Dwarf	Dwarf	Smile	Dewarf	Army	Cherry	Disc	Museum	Troops	Dwarf	Tongue	Onion
Flock	Limb	Ladies	Disc	Salt	Button	Drum	Barrel	Dwarf	Deer	Disc	Infant
Deer	Wound	Wound	Tongue	Infant	Tongue	Tongue	Dwarf	Disc	Tongue	XXX	Blouse
Tongue	Museum	Blouse	Wound	Button	Blouse	Hammer	Limb	Gate	Flock	XXX	Gate
Disc	Helmet	Infant	Ladies	Disc	Deer	Onion	Flock	Limb	Disc	XXX	Tongue
Cherry	Onion	Button	Limb	Wound	Hammer	Essay	Disk	Wound	Cherry	XXX	Cave
Gate	Army	Rose	Cherries	Dwarf	Infant	XXX	Ladies	Museum	Gate	XXX	XXX
Hammer	Cart	Limb	Barrel	Helmet	Ladies	XXX	Blouses	Barrel	Hammer	XXX	XXX
Limb	Deer	Autumn	Blouse	Cart	Limb	XXX	Infant	Button	Limb	XXX	XXX
Museum	Canal	Cave	Infant	XXX	Rose	XXX	Hammer	Hammer	Museum	XXX	XXX
Barrel	Tongue	Drums	Button	XXX	Flock	XXX	Wound	Flock	Barrel	XXX	XXX
Blouse	Button	Barrel	Museum	XXX	Museum	XXX	Button	Deer	Blouse	XXX	XXX
Infant	Chapel	Disc	Hammer	XXX	XXX	XXX	Cave	XXX	Infant	XXX	XXX
Button	Bishop	Essay	Gate	XXX	XXX	XXX	Drum	XXX	Button	XXX	XXX
Wound	XXX	Museum	XXX	XXX	Wound	XXX	Chapel	XXX	Wound	XXX	XXX
Ladies	XXX	XXX	XXX	XXX	Gate	XXX	XXX	XXX	Ladies	XXX	XXX

Table 4.9: Week 2 Pre-Test Participant Word Lists compared to Correct Word List.

	Participants								
Correct Pre-Test List	P2	P3	P4	P6	P7	P8	P9	P10	P11
Stake	Stake	Stake	Stake	Stake	Prince	Stake	Dwarf	Stake	Stake
Dwarf	Dwarf	Dwarf	Motor	Lung	Dwarf	Dwarf	Staff	Dwarf	Dwarf
Motor	Motor	Breast	Bike	Hunter	Plate	Motor	Motor	Motor	Motor
Breast	Breast	Plate	Breast	Queen	Armor	Breast	Breast	Breast	Breast
Plate	Plate	Bishop	Plate	Plate	Stake	Plate	Plate	Plate	Plate
Bishop	Bishop	Stool	Dwarf	Drum	Flesh	Bishop	Stool	Bishop	Bishop
Stool	Stool	Salt	Salt	Bike	Skull	Stool	Bishop	Stool	Stool
Bike	Bike	Bucket	Bucket	Motor	Hunter	Bike	Bike	Bike	Bike
Salt	Salt	Flesh	Spain	Crust	Queen	Salt	Salt	Salt	Salt
Bucket	Bucket	Spain	Italy	Prince	Bishops	XXX	Bucket	Bucket	XXX
Flesh	Flesh	Italy	Bishop	Italy	Tomb	XXX	Flesh	Flesh	XXX
Spain	Spain	Drum	Bible	Spain	Spain	XXX	Spain	Spain	XXX
Italy	Italy	Lung	Queen	Crown	Italy	XXX	Italy	Italy	XXX
Drum	Drum	Tomb	Flesh	Pope	Deer	XXX	Lung	Drum	XXX
Lung	Lung	Badge	Blood	Arrow	Drum	XXX	Wreck	Lung	XXX
Wreck	Wreck	Gift	Tomb	Castel	Salt	XXX	Drum	XXX	XXX
Dummy	Dummy	Dummy	Cave	Dwarf	Bucket	XXX	Dummy	XXX	XXX
Gift	Gift	Hunter	XXX	XXX	Motor	XXX	Gift	XXX	XXX
Hunter	Hunter	Skull	XXX	XXX	Breast	XXX	Skull	XXX	XXX
Skull	Skull	Bible	XXX	XXX	Bike	XXX	Hunter	XXX	XXX
Bible	Bible	Wound	XXX	XXX	Wreck	XXX	Bible	XXX	XXX
Wound	Wound	Queen	XXX	XXX	Dummy	XXX	Queen	XXX	XXX
Queen	Queen	Armour	XXX	XXX	Gift	XXX	Armour	XXX	XXX
Armour	Armour	Wreck	XXX	XXX	XXX	XXX	Wound	XXX	XXX
Tomb	Tomb	XXX	XXX	XXX	XXX	XXX	Tomb	XXX	XXX
Badge	Badge	XXX	XXX	XXX	XXX	XXX	Badge	XXX	XXX
Cabin	Cabin	Cabin	XXX	XXX	XXX	XXX	Cabin	XXX	XXX
Crust	Crust	Crust	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Prince	Prince	Prince	Prince	XXX	XXX	XXX	XXX	XXX	XXX
Deer	Deer	Deer	Deer	Deer	XXX	XXX	XXX	XXX	XXX

Table 4.10: Week 2 Post-Test Participant Word Lists compared to Correct Word List.

	Participants								
Correct Post-Test List	P2	P3	P4	P6	P7	P8	P9	P10	P11
Guinea	Guinea	Guinea	Guinea	Guinea	Lock	Lock	Steel	Guinea	Lock
Rope	Deck	Rope	Rope	Rope	Guinea	Pole	Angle	Lock	Parcel
Parcel	Stain	Parcel	Package	Slope	Angle	Guinea	Stove	Parcel	Guinea
Angle	Flame	Angle	Pole	Lens	Parcel	11	Smoke	Steel	Pole
Lock	Cigar	Lock	Angle	Dish	Crowd	Linen	Flame	Smoke	Rope
Pole	Crowd	Linen	Linen	XXX	Aisle	Angle	Guinea	Cigar	Fuel
Linen	Veil	Eleven	Twist	XXX	Dish	Sketch	Isle	Flame	Crest
Eleven	Pole	Twist	Sketch	XXX	Squash	Veil	Aisle	Deck	Dish
Twist	Rocket	Lens	Eleven	Equation	Flame	Parcel	Fuel	Stain	Stove
Sketch	Parcel	Rocket	Lens	Aisle	Stove	Lens	Twist	Eleven	Squash
Lens	Aisle	Dish	Rocket	Isle	Fuel	Bullet	Crest	Squash	Twist
Rocket	Isle	Sketch	Squash	XXX	Slope	Flame	Stain	Stove	Veil
Dish	Dish	Squash	Dish	XXX	Steel	Fuel	Deck	Smoke	Eleven
Squash	Squash	Deck	Stove	Spill	Rocket	Steel	Parcel	Fuel	Linen
Deck	Crest	Aisle	Deck	Angle	Deck	Dish	Rifle	Bullet	Rocket
Aisle	Bullet	Isle	Aisle	Flame	Isle	Stove	Bullet	Veil	Cigar
Isle	Rifle	Bullet	Isle	Bullet	Eleven	Squash	Rocket	Angle	Smoke
Bullet	Steel	Stove	Bullet	Rifle	Twist	Twist	Rope	Sketch	Bullet
Stove	Smoke	Rifle	Fuel	XXX	Rope	Rifle	Lock	Crowd	Stain
Fuel	Oven	Smoke	Rifle	XXX	Crest	Rocket	Pole	Linen	Deck
Rifle	Flame	XXX	Smoke	XXX	Linen	Smoke	Veil	Rope	Steel
Smoke	Linen	Stain	Steel	XXX	Stain	Slope	Slope	Slope	Flame
Steel	Eleven	Cigar	Slope	XXX	Rifle	Rope	Dish	Aisle	Slope
Slope	Angle	Flame	Cigar	XXX	Lens	Aisle	Lens	Isle	Angle
Stain	Lens	Crowd	Stain	XXX	Sketch	Isle	Sketch	XXX	Sketch
Flame	Sketch	Veil	XXX	Cigar	Veil	Stain	Eleven	XXX	Rifle
Cigar	Diagram	XXX	XXX	XXX	Bullets	Deck	Crowd	XXX	Aisle
Crest	Rope	XXX	XXX	XXX	Smoke	XXX	Squash	XXX	Isle
Crowd	Twist	XXX	Crowd	XXX	Cigar	XXX	Cigar	XXX	Lens
Veil	Lock	XXX	Veil	Veil	Pole	XXX	XXX	XXX	XXX

Table 4.11: Week 1 Lenient Recall Scores *t*-test.

	Pre-Test	*Post-Test*
Mean	0.625454545	0.829090909
Variance	0.057627273	0.025569091
Observations	11	11
Pooled Variance	0.041598182	
Hypothesized Mean Difference	0	
df	20	
t Stat	-2.341528798	
P(T<=t) one-tail	0.014835522	
t Critical one-tail	1.724718243	
P(T<=t) two-tail	0.029671045	
t Critical two-tail	2.085963447	

Table 4.12: Week 1 Strict Recall Scores *t*-test.

	Pre-Test	*Post-Test*
Mean	0.393636364	0.231818182
Variance	0.108365455	0.057076364
Observations	11	11
Pooled Variance	0.082720909	
Hypothesized Mean Difference	0	
df	20	
t Stat	1.319474534	
P(T<=t) one-tail	0.100958498	
t Critical one-tail	1.724718243	
P(T<=t) two-tail	0.201916997	
t Critical two-tail	2.085963447	

Table 4.13: Week 2 Lenient Recall Scores *t*-test.

	Pre-Test	*Post-Test*
Mean	0.634444444	0.856666667
Variance	0.070977778	0.025925
Observations	9	9
Pooled Variance	0.048451389	
Hypothesized Mean Difference	0	
df	16	
t Stat	-2.141611191	
P(T<=t) one-tail	0.02397995	
t Critical one-tail	1.745883676	
P(T<=t) two-tail	0.0479599	
t Critical two-tail	2.119905299	

Table 4.14: Week 2 Strict Recall Scores *t*-test.

	Pre-Test	*Post-Test*
Mean	0.425555556	0.204444444
Variance	0.090602778	0.050677778
Observations	9	9
Pooled Variance	0.070640278	
Hypothesized Mean Difference	0	
df	16	
t Stat	1.764780209	
P(T<=t) one-tail	0.048338899	
t Critical one-tail	1.745883676	
P(T<=t) two-tail	0.096677798	
t Critical two-tail	2.119905299	

Table 4.15: Week 1 Standard Descriptive Statistics for Lenient Pre-Test Scores.

Mean	0.625454545
Standard Error	0.072379852
Median	0.67
Mode	#N/A
Standard Deviation	0.240056811
Sample Variance	0.057627273
Kurtosis	-1.255695324
Skewness	0.094837851
Range	0.73
Minimum	0.27
Maximum	1
Sum	6.88
Count	11

statistics calculated based on the results of the second week of the experiment are shown in these four Tables: 4.19, 4.20, 4.21, and 4.22.

Through the boxplot Figures 4-4 and 4-5, one can see the distribution of test scores in both pre-test and post-test for lenient and strict scoring, for the first week of the experiment, displaying a clearly visible increase in lenient scores from pre-test to post-test conditions, while displaying a decline in strict score from pre-test to post-test. Similar trends, albeit more pronounced, can also be seen in the boxplot Figures created based on the data from the second week of the experiment: 4-6 and 4-7.

The time required to place all the items in the palace or complete the collectible phase, for each participant, can be seen in Table 4.23 and Table 4.24 for week 1

Table 4.16: Week 1 Standard Descriptive Statistics for Lenient Post-Test Scores.

Mean	0.829090909
Standard Error	0.048212683
Median	0.93
Mode	0.93
Standard Deviation	0.15990338
Sample Variance	0.025569091
Kurtosis	-0.808517202
Skewness	-0.827382829
Range	0.47
Minimum	0.53
Maximum	1
Sum	9.12
Count	11

Table 4.17: Week 1 Standard Descriptive Statistics for Strict Pre-Test Scores.

Mean	0.393636364
Standard Error	0.099254244
Median	0.33
Mode	0.03
Standard Deviation	0.329189086
Sample Variance	0.108365455
Kurtosis	-1.228447002
Skewness	0.487439209
Range	0.87
Minimum	0.03
Maximum	0.9
Sum	4.33
Count	11

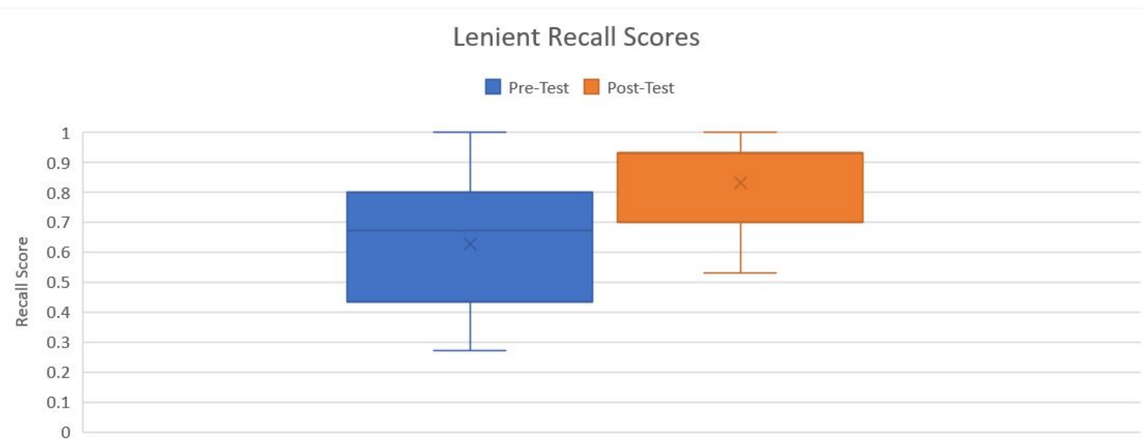


Figure 4-4: Week 1 Lenient Recall Scores Boxplot.

Table 4.18: Week 1 Standard Descriptive Statistics for Strict Post-Test Scores.

Mean	0.231818182
Standard Error	0.07203305
Median	0.13
Mode	0.13
Standard Deviation	0.2389066
Sample Variance	0.057076364
Kurtosis	1.336481402
Skewness	1.479283683
Range	0.74
Minimum	0.03
Maximum	0.77
Sum	2.55
Count	11

Table 4.19: Week 2 Standard Descriptive Statistics for Lenient Pre-Test Scores.

Mean	0.634444444
Standard Error	0.088805516
Median	0.57
Mode	0.3
Standard Deviation	0.266416549
Sample Variance	0.070977778
Kurtosis	-1.647047628
Skewness	0.070255327
Range	0.7
Minimum	0.3
Maximum	1
Sum	5.71
Count	9

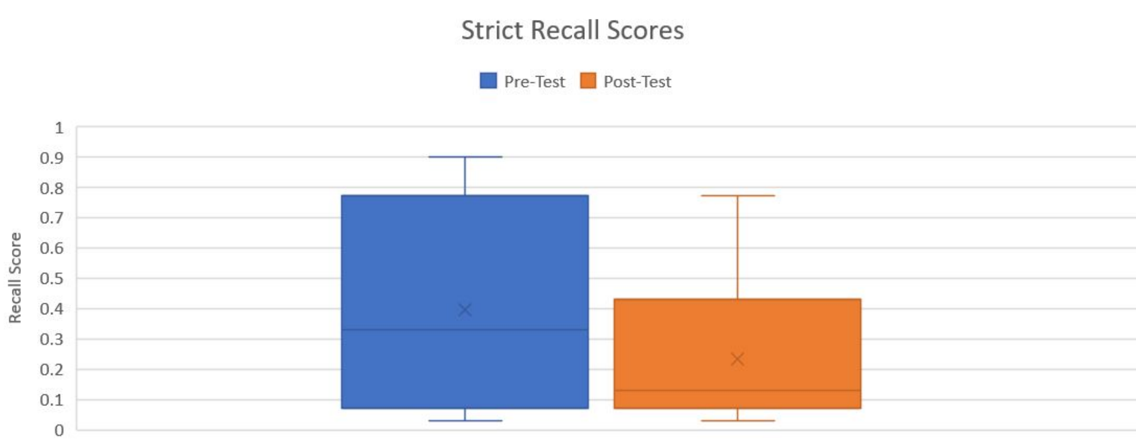


Figure 4-5: Week 1 Strict Recall Scores Boxplot.

Table 4.20: Week 2 Standard Descriptive Statistics for Lenient Post-Test Scores.

Mean	0.85666667
Standard Error	0.05367081
Median	0.9
Mode	0.97
Standard Deviation	0.16101242
Sample Variance	0.025925
Kurtosis	4.60615472
Skewness	-2.0069488
Range	0.5
Minimum	0.47
Maximum	0.97
Sum	7.71
Count	9

Table 4.21: Week 2 Standard Descriptive Statistics for Strict Pre-Test Scores.

Mean	0.42555556
Standard Error	0.10033432
Median	0.3
Mode	0.3
Standard Deviation	0.30100295
Sample Variance	0.09060278
Kurtosis	-0.0065618
Skewness	0.85713107
Range	0.9
Minimum	0.1
Maximum	1
Sum	3.83
Count	9

Table 4.22: Week 2 Standard Descriptive Statistics for Strict Post-Test Scores.

Mean	0.204444444
Standard Error	0.075039084
Median	0.1
Mode	0.1
Standard Deviation	0.225117253
Sample Variance	0.050677778
Kurtosis	0.677789324
Skewness	1.587070675
Range	0.53
Minimum	0.07
Maximum	0.6
Sum	1.84
Count	9

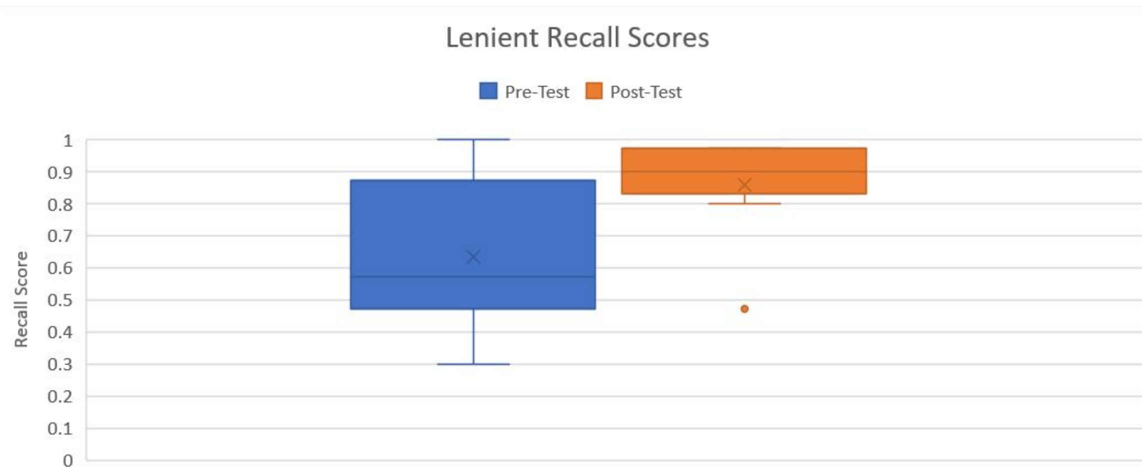


Figure 4-6: Week 2 Lenient Recall Scores Boxplot.

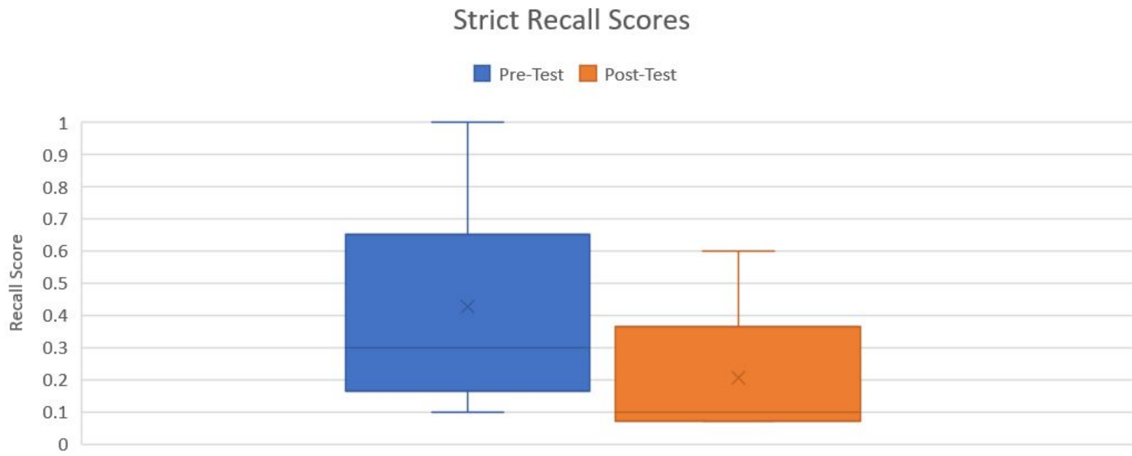


Figure 4-7: Week 2 Strict Recall Scores Boxplot.

Table 4.23: Time taken for participants to collect all Collectibles and place all Placeables in Week 1.

(in seconds)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Time taken to collect all Collectibles	146.3	360.4	N/A	141.3	117.1	N/A	265.5	N/A	N/A	N/A	N/A
Time taken to place all Placeables	601.9	616.3	602.3	729.7	627.7	717.4	567.0	N/A	778	N/A	N/A

and 2 of the experiment respectively. Some timings for collectible phases were lost due to the application freezing unexpectedly and becoming unresponsive until Unity was restarted forcefully, with participants P1-P7. Participants P8-P11 went through the experimental procedure under the thesis supervisor's supervision rather than the author's and many phase timings were not recorded or were lost. All of these lost times were marked with 'N/A' in the Table.

Brigham – Please use: https://www.tablesgenerator.com and shrink the first column (ie., make it double height), that way it will all fit the width of the page for Table 4.23 and Table 4.24

Table 4.24: Time taken for participants to collect all Collectibles and place all Placeables in Week 2.

(in seconds)	P2	P3	P4	P6	P7	P8	P9	P10	P11
Time taken to collect all Collectibles	283.5	134.2	95.2	N/A	104.3	N/A	N/A	N/A	N/A
Time taken to place all Placeables	516.9	285.2	347.3	482.2	514.5	568	819	372	508

Chapter 5

Discussion

5.1 Pre-Test

After completion of their mental rotation tasks, participants were given 15 minutes to memorize a list of 30 words, using a single piece of scrap paper if they wanted to draw or write anything down to help with whatever mnemonic technique they decided to use. Participants almost always used all of the 15 minutes allotted to them for studying the list, with some participants believing they were ready about 2 or 3 minutes before finishing their time limit. Various studying methods were used for this phase, as indicated by the participants through the scrap paper given to them and the questionnaire at the end of the experiment where people reported what strategies they used. Participants P1, P7, and P9 created a story out of the words in the list given to them, drawing a series of events on a sheet of paper as participant P1 calls a 'storyboard'. P1's notes drawn while making their story out of the words can be seen in Figure 5-1.

P2, P3, and P5 each made associations between words to remember them, linking two words into a single combined image, or creating an acronym out of different words to associate. An example of some notes drawn during use of this memorization strategy, by P5, can be seen in Figure 5-2.

P4, P6, P8, P10, and P11 used repetition, trying to remember the words by repeating the words to themselves out loud and by writing them down over and over.

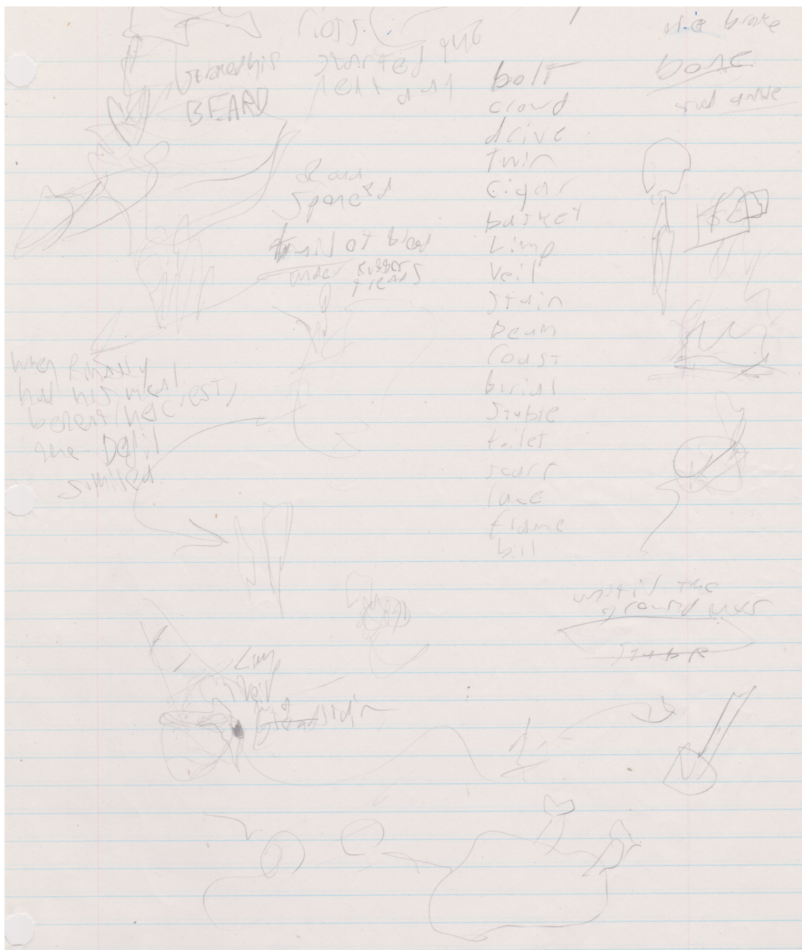


Figure 5-1: Notes drawn by participant P1 when creating a story to memorize the words in the pre-test word list.

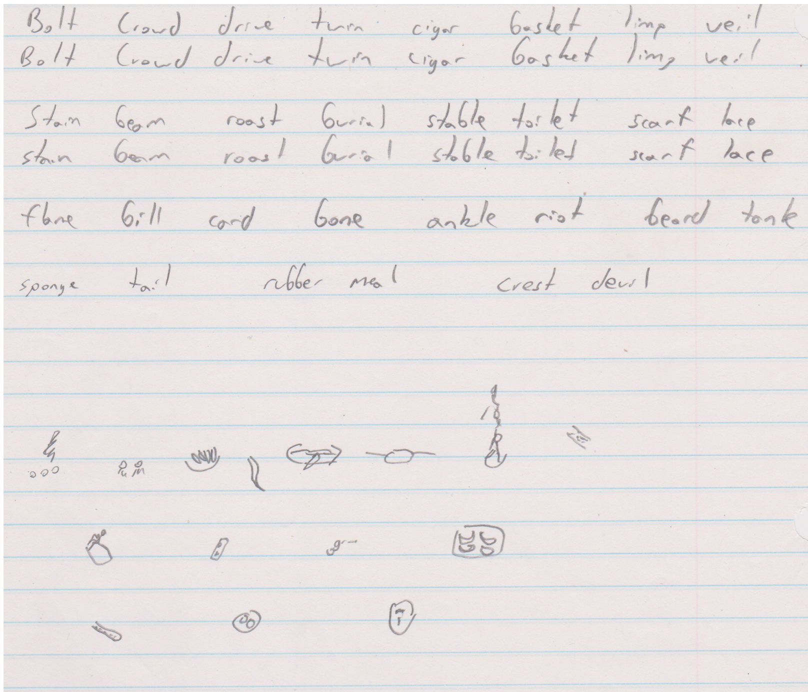


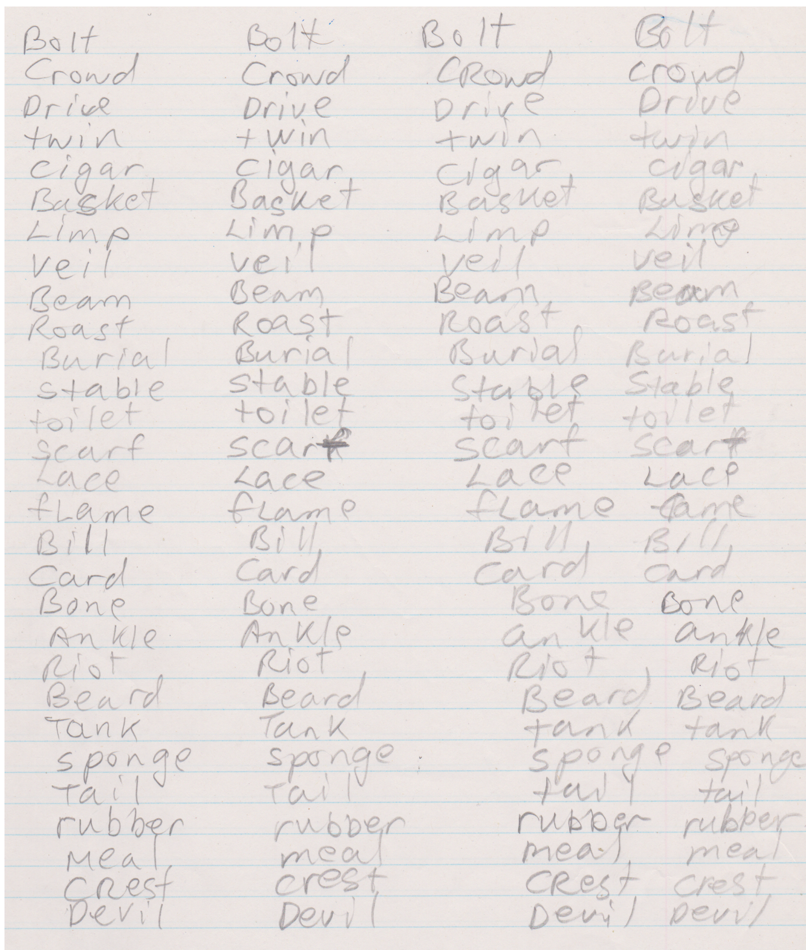
Figure 5-2: Notes drawn by participant P5 when associating words together into combined images to memorize the words in the pre-test word list.

Sometimes this included making an acronym that associated the first letters of words together, and the participant would repeat the acronym instead. An example of the notes drawn while using this method, as done by participant P6, can be seen in Figure 5-3.

It is important to note that some participants chose to switch which strategy they used on the pre-test between weeks 1 and 2 of the experiment, if they did both weeks. The change in strategy in the pre-test often led to much different results than the week prior. For example, P3 used an acronym association technique in the first week, and their notes while using that technique can be seen in Figure 5-4.

In the second week, they used an association between drawn images of the words that they represent, as shown in Figure 5-5.

Their pre-test results improve significantly through this switch, and they mentioned after the experiment that they were inspired to use the new strategy after



Bolt	Bolt	Bolt	Bolt
Crowd	Crowd	CRowd	crowd
Drive	Drive	Drive	Drive
twin	twin	twin	twin
cigar	cigar	cigar	cigar
Basket	Basket	Basket	Basket
Limp	Limp	Limp	Limp
veil	veil	veil	veil
Beam	Beam	Beam	Beam
Roast	Roast	Roast	Roast
Burial	Burial	Burial	Burial
stable	stable	Stable	Stable
toilet	toilet	toilet	toilet
scarf	scarf	scarf	scarf
Lace	Lace	Lace	Lace
flame	flame	flame	flame
Bill	Bill	Bill	Bill
Card	Card	card	card
Bone	Bone	Bone	Bone
Ankle	Ankle	ankle	ankle
Riot	Riot	Riot	Riot
Beard	Beard	Beard	Beard
Tank	Tank	tank	tank
sponge	sponge	sponge	sponge
Tail	Tail	tail	tail
rubber	rubber	rubber	rubber
Meal	meal	meal	meal
CRest	crest	CRest	crest
Devil	Devil	Devil	Devil

Figure 5-3: Notes drawn by participant P6 when using oral and written repetition to memorize the words in the pre-test word list.

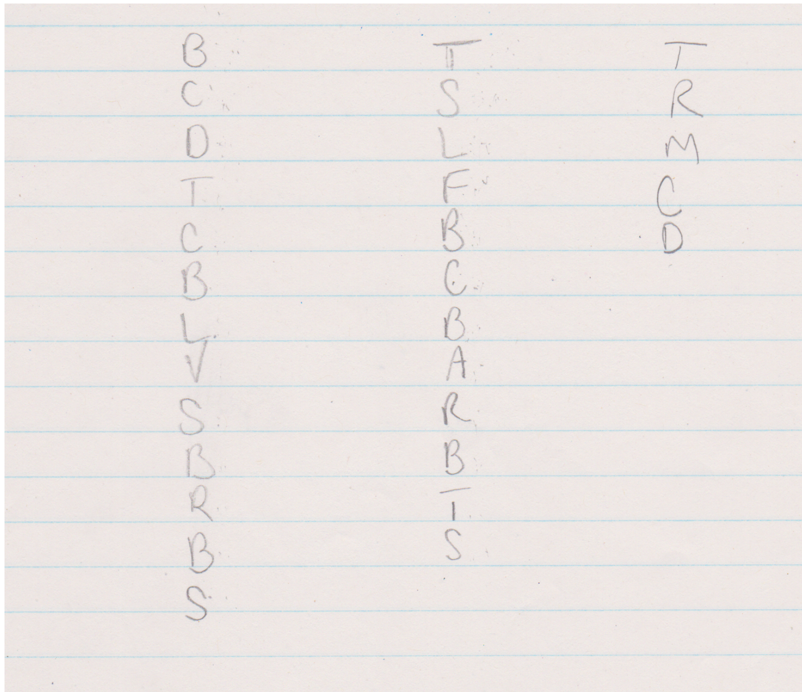


Figure 5-4: Notes drawn by participant P3 in the first week using associations through acronyms to memorize the words in the pre-test word list.

Figure 5-5: Notes drawn by participant P3 in the first week using associations through pictures to memorize the words in the pre-test word list.

using the method of loci on the previous week, desiring to use the effectiveness of imagery in their studying technique rather than simply text.

No significant patterns were observed to correlate the mental rotation task results with how well a given participant did with the VR MoL phase of the experiment. Higher performance on mental rotation tasks, and therefore better spatial cognitive abilities, were observed to generally lead to better recall in participants in Vindenes et al. (2018). It is hypothesized that if this experiment had been conducted with more participants, a pattern may have emerged to follow this trend. As much as they may try to focus on a task, any given participant could have gotten distracted by something and had worse performance than what truly represents their spatial cognitive abilities. Between the first and second week of the experiment, participants who participated in the second week of the experiment had different results than in the first week. The differences in their performances were quite significant in some cases, as can be seen most notably with participant P4, whose accuracy in the mental rotation tasks between week 1 to week 2 dropped 33%. Meanwhile, participant P6's performance increased by 20%.

5.2 Participant Training Phase in the VR Environment

On average, it took approximately 3 minutes and 3 seconds for participants to collect all of the Collectibles in the memory palace during the training phase of the experiment. In the first week, this average time was 3 minutes and 26 seconds and in the 2nd week it was 2 minutes and 34 seconds. Participants in the second week of the experiment reported feeling much more comfortable with the system than in the previous week and predictably took less time to complete the exploration of the memory palace through collecting Collectibles. In the first week of the experiment, participants needed to use some time to get comfortable with the motion sensors from KAT VR to learn how to walk in the simulation. Participants generally found two ways to use the sensors, where about half of the participants raised their knees high and marched or jogged to move, while others raised and lowered their heels to move slower and more accurately. In the second week of the experiment, participants were more eager to move through the environment at faster speeds. For almost all participants, the sensors were said to be awkward to use at first and over time they became comfortable with them.

Due to sensors being used solely instead of with a frictionless platform, participants had to focus on trying to walk or jog on the spot rather than walking naturally in the direction they wanted to move. This understandably lessened immersion, and it is suggested for future work to make use of a frictionless platform optimally, or at least an omnidirectional treadmill to maintain immersion and not have participants thinking about their position in the real world. Overall though, it is believed that the sensors added much more immersion compared to an environment without them, and almost all participants seemed to experience this increased immersion, sometimes to the point of forgetting that they needed to walk in place rather than normally. It is also hypothesized that the sensors reduced potential nausea from VR. Most participants in the experiment had little experience with VR prior to participating and only one person, participant P2, experienced any sort of nausea that required them to take a short break from VR after the training phase of the experiment before completing the VR MoL phase. This may have resulted in worse results for them compared to what they could have potentially had, due to the loss of immersion from leaving VR for a certain amount of time during the experiment procedure.

Participants collecting Collectibles seemed to move in mostly random paths, and no significant patterns were observed between participants.

5.3 VR MoL Phase

On average, it took approximately 9 minutes and 28 seconds for participants to place all of the Placeable items in the VR MoL phase. In the first week, this average time was 10 minutes and 55 seconds and in the 2nd week it was 8 minutes and 10 seconds.

The decrease in time is likely due to the participants getting more comfortable with the VR MoL system, as they stated was the case after the experiments in the second week. Participants felt comfortable with the remaining time given to them for reviewing their placements (the remainder of their 15 minute time limit to complete the VR MoL phase), and no participant felt the need to rush the procedure. Some participants did not need all of the allotted time and left the environment a minute or two early.

Some participants in the experiment were able to recall 100% of the words they were told to memorize, or nearly all of them, in one or both of the recall tests (pre-test and post-test). It is believed that the difference between the environments, and the full benefits of the method of loci, would have been observed more clearly had the word lists contained 40 words as originally planned, if not more. For some, 30 words in a list is simply not challenging enough, as was discovered in some of the resulting scores of this experiment. If enough time were available in a future study, it is recommended to follow the suggested word list size of 40 from Ross & Lawrence (1968), or a list of an even larger size than that if possible. Another concern was nausea from the virtual reality environment if participants were in it for too long, but it is believed that much of this was in fact negated by the natural walking movements participants could use, as afforded by the worn KAT VR motion sensors. If the word list was to be expanded, it would make sense to also have participants use a frictionless platform optimally, or otherwise an omnidirectional treadmill, so that movement would, in theory, feel natural enough that nausea from the VR environment for first-time users of VR would be reduced to a minimum. The time required for the VR MoL phase would have to be increased as well, perhaps using the 15 minute time limit for studying 30 words as a guide (30 seconds per word). A 40 word list then, it is hypothesized, would require about 20 minutes to study. This would also increase the time limit for studying the word list on paper, making the full experiment time increase, but it is believed that when studying on paper the increased time given will not aid the memorizer as much as having increased time in the VR environment. In Ross & Lawrence (1968), where the MoL was classically defined, it was suggested that some significant space should

Figure 5-6: A heatmap showing where participants placed Placeables in the virtual memory palace (Placeable locations are denoted by red spheres).

be between each item to be memorized. Optimally, the memory palace would also be expanded into a larger space, providing more space between items memorized. 40 words seems perfectly doable in the current environment, but it requires some strategizing on the participant's part to make sure that they make use of all rooms effectively.

It is important to note that there were specific rooms in the virtual memory palace created that seemed to be either completely forgotten by participants or very seldom used. The placements of Placeables by all participants over both weeks of the experiment can be seen in the heatmap shown in Figure 5-6, where areas with red spheres represent places that Placeables were placed.

The least used parts of the memory palace were the storage room, the smaller of the two bedrooms, and the recreation room. These rooms make up the majority of one side of the apartment design. There are two reasons hypothesized to be why this happened. First of all, the rooms were not as visibly accessible from the large central space in the apartment compared to the office, bathroom, and large bedroom. Since there is only one door to the storage room, and it is hidden inside the recreation room, the room is often forgotten compared to the bathroom that has a visible door directly to it, and a second entrance from the large bedroom. The small bedroom was also often unseen, with its entrance invisible when looking into the apartment from the entrance. The office was similarly missed in several cases for the same reason, but not as often as the small bedroom. It seems that an optimal memory palace design would have entrances to each available room always visible from the central space of the apartment. This way people would be more encouraged to make use of all rooms available to them.

The second reason for low usage of the rooms on one side of the apartment was hypothesized to be that those rooms did not serve as clear of a purpose to the participant as the rooms on the other side of the apartment. The smaller bedroom, the recreation room, and the storage room are rooms that not all participants even had in their own homes, and they were less common compared to rooms that are in nearly any home, such as a kitchen, dining area, living area, bathroom, large bedroom, office, etc. It was hypothesized that this was the reason why, out of the two rooms with invisible entrances when standing in the kitchen area, on opposite ends of the apartment (the office and the small bedroom), the office ended up getting more items placed in it compared to the small bedroom. In an optimal memory palace design, it may make more sense to have fewer rooms, all of clear purpose and common, but larger than their usual size to accommodate all the items to be placed.

The image selector used in the experiment by participants to choose which image would be used with created Placeable objects was something suggested by other studies but entirely new. It was well received by participants, who enjoyed the degree of personalization in their Placeable items and likely created stronger memory associations with the pictures chosen, by choosing them. However, there were certain problems with the image selector that sometimes led to participants being unable to choose the image they desired of the three given to them. The selector would sometimes spawn inside of an object or wall the participant happened to be looking at, and the choices would be invisible or only partly visible. Also, if the participant was standing off-center from the available real world space to conduct the experiment in, the selector would spawn in the wrong location, sometimes right on top of the participant, leading to a selection of an image before seeing any of them. The off-center positioning issue would be solved in a future study if resources were available to get a frictionless platform or omnidirectional treadmill that would keep the participant centered at all times. As for the spawning of the selector inside of objects, a redesign of where it spawns would be needed. Having the selector spawn at specified locations in the apartment was considered, using whichever location was closest to the participant, but it seemed much more convenient to the participant to have it spawn in front of them always so that they immediately knew where it would be. Further research is needed to find the most convenient way to select images.

Participant P4 also commented that in both weeks of the experiment, the associations between the image and the word given, in the virtual reality environment, helped a great deal in trying to memorize items. It was common among participants to say that in the recall test they remembered the images of the things they placed long before they remembered what word they were associated with. It is hypothesized that in an optimal scenario where participants can use any image on the Internet for a given Placeable they are studying, that the effect of personalizing the images on improving memory recall would become heightened further.

5.4 Post-Test

When using the method of loci in VR, on average, participants had their lenient scores increase by 20.4% in the first week of the experiment, as observed in the difference between the means of their pre-test and post-test lenient scores. This means that people usually remembered 20.4% more of the items from the list, meaning that their memory recall was improved significantly. In the second week, this lenient score improvement rose to 22.2%.

Overall, the change from pre-test to post-test studying methods did not produce a significant enough improvement or deterioration in strict scores for participants. Some participants experienced no difference, some experienced improvement, and some experienced deterioration in their strict score results. The t-test done on participant lenient scores however shows that there was a significant change from pre-test to post-test studying methods.

It is important to remember that participants were given very little time (less than half an hour), to familiarize themselves with the MoL and the VR environment used to virtually simulate the technique. If participants already showed significant improvement in their lenient scores through their first time using the VR MoL environment, compared to a studying method on paper that they are very comfortable with and have likely used for the majority of their lives, then it is likely that these improvements would be even more evident had they been given more time and attempts to get familiar with the system. If given several chances to use the environment in a future study, it is believed that the results would be far more encouraging than even the ones presented here with limited participants and time. The fact that the improvement was already significant in this study just further solidifies how effective the MoL really is for memorization. There is also a point to be said about the potential improvements to long-term memory as opposed to traditional studying techniques. Perhaps in a future study, participants could be asked if they can remember the words from the pre-test and post-test phases of an attempt they did several weeks ago. It is hypothesized that this would show more favorable results for the MoL, and this idea of long-term memory being improved through the MoL has been suggested by multiple other studies such as Optale et al. (2010).

Through observing participants try to implement the method of loci in the memory palace on their given VR MoL phases of the experiment, it became evident over time that there were different strategies in which one could use to complete the task despite being told to use a specific mnemonic technique. It is of the opinion of the author of this thesis that the definition of the method of loci is perhaps too loosely defined. While almost all participants experienced improvement in their lenient scores when using the VR MoL environment to study, it seemed from observations that the strict score of participants depended greatly on how they used the method of loci, in other words, what their strategy was for using it. The lenient score of a given participant also seemed to be increased when using particular strategies over others. The range of strategies participants used can be placed into the following categories:

- Associating items with each other in groups and thinking less about the environmental connections,
- Associating items to their best locations in the environment while forgetting their order,
- Placing items in a path through the environment without thinking about specifically where they are placed,
- and lastly, moving through the environment in a specific path and placing items in their most relevant locations along that path to maintain both environmental associations and the order of the items. These four categories of strategies are ordered from what seemed to be the least effective to the most effective in regards to getting the highest combination of lenient and strict scores.

Participant P4 is a significant example when discussing strategies for implementing the method of loci. P4 used the first strategy mentioned in the first week, then the last one mentioned in the second week. When they changed their strategy, their strict and lenient score both improved significantly. In the second week, P4 had a lenient score 17% higher than the previous week, and a strict score 47% higher. In the first week, P4 placed almost all of their items in the main room of the apartment with the living room, dining room, and kitchen combined. The placements were not very much inspired by their link to their placement location, as opposed to their link to each other. It was a way of associating the words together, forming them into related

Figure 5-7: Locations where participant P4 placed their Placeable items in the first week of the experiment (as denoted by the red spheres).

groups. Also, being cramped into a single space, the participant did not make use of the full memory palace. There was no visible order to the placements either. The locations where P4 placed items in the first week can be seen in Figure 5-7.

In the second week of the experiment, participant P4 decided to use nearly all of the rooms in the palace, walking in a specific path through the many rooms and placing items as they walked, visibly in the order they were given to them. Rather than placing items according to where they would best fit in the entire palace, instead participant P4 placed them where they seemed to best fit in the current position of their path through the memory palace. For example, when the word 'pole' came up, it was placed on a lamp that had a pole in its base next to P4's current location.

Figure 5-8: Locations where participant P4 placed their Placeable items in the second week of the experiment (as denoted by the red spheres).

Similarly, the word ‘smoke’ was placed off of the balcony’s edge when P4 walked past the balcony at the same time as receiving the word. By doing this, they continued to make associations between the environment and the given items, thinking carefully about their locations, while still retaining the order of the items according to a walked path. It may require more thinking and imagination to come up with some kind of connection between a nearby location and the item to be placed (placing the word ‘bullet’ in the bedroom for instance), but that extra thinking could lead to an even more effective association. The locations where P4 placed their Placeables in the second week can be seen in Figure 5-8.

An important thing to note is that all participants believed when they answered the questionnaire, that they had followed the method of loci as it was meant to be, or they at least tried to. Being famously complex, it is perhaps not surprising that participants did not fully grasp the strategy on their first or second attempt using it. However, it seems that if the definition of the MoL were more closely defined to specifically talk about the most effective way to use the method, making specific mention to placement of items in the most relevant places for them *along a specific path* in the environment, maybe participants would grasp the technique earlier on and be able to use it effectively with less training.

Some results in the post-test are believed to have been affected by uncontrollable factors related to specific participants. Some participants (participants P1, P2, P5, and P8) had seen the memory palace layout before the experiment, but only participant P1 knew it in great detail. Participant P3 was observed to be, and explained, that they were quite distracted from the post-test task in week 2 of their experimental results, due to stress from work. We hypothesize that this is the reason P3's post-test lenient score dropped in week 2 compared to week 1, rather than what was expected to be an improvement.

5.5 Questionnaire

In the questionnaire after the experiment, participants were asked to talk about their pre-test memorization technique (as previously discussed), their experience level in VR, whether they actually used the method of loci, their confidence in their answers in the pre-test versus the post-test, how immersive they found the environment, whether they knew about the MoL beforehand, and whether they would use the system in a real-life example to study something. The questionnaire was given out during the first week of the experiment only. In the second week, participants were asked if they felt more comfortable using the system, to which all participants agreed that they did. A summary of the questionnaire's results can be seen in Table 5.1.

Table 5.1: Summary of Questionnaire Results.

Very little/No experience with VR	73%
Somewhat experienced with VR	27%
Very confident in Pre-Test	46%
Somewhat confident in Pre-Test	27%
Not very confident in Pre-Test	27%
Very confident in Post-Test	72%
Somewhat confident in Post-Test	9%
Not very confident in Post-Test	18%
Somewhat immersed	18%
Very immersed	82%
Created a story to remember words in pre-test	27%
Used repetition to remember words in pre-test	45%
Used association to remember words in pre-test	27%
Believed they used the MoL as instructed	100%
Had a little prior knowledge of the MoL	36%
Would use the system in a real-life scenario	91%

How experienced any given participant was with VR seemed to have negligible impact on their results. Whether experienced or not, participants seemed to have the same range of lenient and strict scores, without any specific patterns related to their VR experience.

As previously discussed, all participants believed that they had used the method of loci, and so compliance was not an issue in this experiment as it had been with older people in Verhaeghen & Marcoen (1996). If anything, it is believed that if a participant did not follow the MoL perfectly it was due to the technique being loosely defined and a lack of experience in the participants (no one reported knowing the MoL quite well, only vaguely at best). Participant experience with the MoL did not seem to impact results in any significant way, in the limited pool of participants in this study. If there were any participants that knew the technique well, a pattern may have emerged.

For all but one participant (participant P5), confidence in their answers given on the pre-test versus the post-test was reported on the questionnaire to have improved. For another participant (participant P1), they felt they were more confident with remembering a large number of items, but less confident in the order in which they remembered them. For both of these participants, their lenient scores improved from already being quite high, from pre-test to post-test. However, their strict scores dropped from being very high in the pre-test to being very low in the post-test. It is hypothesized that the reason for these results has something to do with the strategy they used when using the MoL. Both of these participants went about the environment looking for the best place to place each individual item, while forgetting about the order of the items. Had the order been preserved by walking through the environment in a specific path and only placing items in nearby, yet relevant areas, it is believed that their strict scores would have been much higher and with that, their confidence in their post-test results. Raised confidence due to using the VR MoL environment was expected to occur, as previously observed in other studies.

Participants were asked to rate the immersiveness they felt in the experiment based on a scale from 1 to 5, where 1 would be the least immersive. Two participants rated it as a 3, three as a 4, and six as a 5. For most participants, the immersiveness one felt in the experiment seems to reflect how well they performed in the post-test (as far as their lenient score) after using the VR MoL environment to study the word list given to them. Those who rated the immersiveness lower (1, 2, or 3) tended to have worse performance when compared to those who rated the immersiveness as high (4 or 5). Higher immersiveness leading to better recall is clearly shown to be the trend here, and it is a trend observed in multiple other studies such as Krokos et al. (2019), Huttner & Robra-Bissantz (2017), and Huttner, Robbert, & Robra-Bissantz (2019). This further highlights the need for a more immersive memory palace experience for better recall results, perhaps starting with using a frictionless platform or omnidirectional treadmill instead of motion sensors for more natural navigation that does not leave participants thinking about their position in the real world while in the virtual one. Other possible improvements that were considered but not used in this study were tactile feedback when holding and dropping placeables, as well as using the edge of a real world surface to simulate the feeling of being on the edge of something like a balcony or the edge when standing on a bed.

All participants except one agreed that they would use the VR MoL environment system as a way to memorize things in a real-life situation. Participant P3 said that it was fun and slightly less stressful compared to traditional memorization. Participant P1, who used a MoL strategy that did not take into account the order of the items, believed it would be effective as long as the memorized information did not need to be ordered. Some participants agreed with this sentiment, while others believed it was effective for ordered memorization. Those who thought it was not as effective for ordered memorization did tend to have worse strict scores compared to those who thought it would be effective for ordered memorization. Participant P7 believed it would be more effective if they had a more familiar environment to use, such as a simulated version of their real home, or just being given more time to get comfortable with the current environment. Only participant P9, who had 100% on their lenient score for both pre-test and post-test in week one when they did the questionnaire, stated that they would not use the technique, saying that they did not think it was practical to use over traditional techniques. However, in the second week, P9 recalled 10% more with VR MoL compared to their traditional studying technique.

Chapter 6

Conclusion

6.1 Summary

In this thesis, a new virtual memory palace simulation was developed for use of the method of loci mnemonic technique, using virtual reality technology. This simulation took into account numerous suggestions, predictions, and past results from other studies of virtual memory palaces to try and improve upon the design of the virtual memory palace and get closer to an optimized solution. With the newly designed memory palace, a group of participants tested whether they could use the system to memorize a list of words more effectively than with traditional studying techniques. It was found that participants on average could remember approximately 20.4% more words when using the virtual memory palace for the first time, and various insights were observed that could potentially further boost memory recall improvements in future VR MoL studies. When participants used the system a second time they remembered approximately 22.2% more compared to traditional studying techniques. With such encouraging results, it is hoped that further studies will be done into the subject of VR MoL, perhaps leading to further encouragement for people to make use of a VR MoL tool in their daily lives for general memorization. There is great potential for this technology especially among students studying new topics and those whose memory recall has gotten worse over the course of their lives. VR MoL holds a potential that applies to everyone, offering the chance for a boost in memory recall for even those not particularly in need of it.

6.2 Conclusions

It was discovered that through using the virtual memory palace system designed in this thesis for the method of loci, participants could remember 20.4% more non-spatial information compared to traditional studying techniques on their first use of the system. On their second use of the system, they remembered 22.2% more non-spatial information. Those who felt more immersed were found to have better memory recall compared to those who did not feel as immersed, which is consistent with the results of other previous studies. Recalling the order of items with the method of loci seemed to be tied to participants who focused on using a method of loci strategy that kept close attention on the order of items given to them. Overall, it is believed that it can be concluded that the VR MoL system designed in this thesis has produced encouraging recall results that outline its potential usefulness as a futuristic memory recall tool to be used by those who may need or desire recall improvements.

6.3 Limitations

During the creation of this thesis, the arrival of COVID-19 led to multiple limitations in the research. Participants were selected through convenience sampling rather than random sampling, and were quite limited to only those allowed to be in close vicinity of the author or the thesis supervisor. The situation also led to the inability to get a frictionless platform such as one of KAT VR's KAT Walk products, leading to the inclusion of KAT VR's KAT Loco worn motion sensors instead.

Due to concerns about first-time users of VR getting nausea, as well as time constraints, the word lists that participants were tested with were limited to 30 words rather than the minimum of 40 words suggested by Ross & Lawrence (1968).

6.4 Future Work

There are a number of suggestions for future work with VR MoL that can be obtained from this study and are further discussed in Chapter 5 of the thesis. Greater immersion has been observed to clearly result in better recall, as is evident from comparisons between how well people did and their rated level of immersion in the questionnaire at the end of the experiment. This is also a trend that has been observed in other previous studies. We suggest that in a future study a frictionless platform be used for walking around the memory palace, such as KAT VR's KAT Walk products. Alternatively an omnidirectional treadmill could be used, but it may not feel as smooth, and may make more noise, than a truly frictionless platform, leading to less immersion for a participant (more research is required to confirm this). This was originally planned to be used for this thesis, but due to time constraints and complications from COVID-19, it could not be arranged. Not only would further immersion lead to better recall, but it is hypothesized to further reduce feelings of nausea experienced by participants and allow for longer length experiments especially with participants trying VR for the first time. Immersion may also be able to be increased through emotional stimuli of some sort in future studies, such as making someone feel the edge of the balcony beneath their feet, simulating standing on the edge of something one could potentially fall off of.

Another suggestion for future studies would be to increase the length of the word lists used to test participants to at least 40 words, as suggested by Ross & Lawrence (1968), if not more than 40. A word list of 30 words proved to be not enough of a challenge for some participants to clearly see the improvements in memory recall due to using the method of loci versus traditional studying techniques. This was not done in this thesis due to time constraints and concerns about feelings of nausea in participants, but with the combination of a more immersive walking method such as a frictionless platform it is believed that longer word lists could be used without issue as long as time permits. In this experiment, 30 seconds per word to be memorized seemed like a comfortable amount of time for participants to complete the VR MoL studying phase of the experiment, but the time required for studying may need to be investigated further.

It is also suggested that further studies into VR MoL try to investigate the effects on recall performance from allowing participants increased training time with the VR MoL system. We believe that with more chances to try the system and get familiar with both the VR equipment and the constructed apartment palace environment, participants could improve on their recall scores.

Defining the MoL more strictly to participants to enforce an effective memorization strategy may prove effective as well, especially after they have used the system multiple times. For example, participants could be told a more detailed description of the technique from the start of the VR MoL phase that outlines how they should look for locations that seem to memorably match with their object in their nearby vicinity (rather than just the best location in the whole palace), while following a defined, non-overlapping path through the rooms that they choose for themselves. The path between words in the memory palace may also become more memorable if one has the number in the original ordered list words, of the word to be memorized, on Placeables when they are placed. The first word would have a '1' on it, the second a '2', and so on.

It may also prove useful to study how well someone can remember words from the first time they used the system, several minutes, days, or weeks later, to investigate the power of VR MoL in terms of long-term memory. Their recall could be compared against how well they recall what they studied in a traditional manner on the same day. Numerous studies have already shown the usefulness of the MoL for long-term memory recall, but perhaps with further refinement of the virtual memory palace simulation, improvements to long-term memory could be increased far more than with a traditional MoL approach.

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Appendices

Appendix A

Experiment Protocol (Script)

1. Make participants complete 5 training mental rotation tasks, and 10 testing rotation tasks.

2. Record their results into an excel file.

3. Give 15 minutes (max) for participant to study a list of 30 words and memorize as many as possible, in order if possible. (Pre-test word list print off)

4. Give 5 minutes (max) for participant to write down every word from the list, in order if possible, in another room. (Pre-test testing paper print off)

5. Explain the 'Method of Loci' using the following description: "In this method, memory is established from places and images. If we wish to remember an object, we must first imagine that object as an image, and then place it in a location. If we wish to remember a list of objects, then we must make a path out the many locations. The easiest way would be to imagine a familiar environment and place the imagined objects inside it. Then, you can pick up the objects as you imagine navigating the environment, thereby remembering the object list in order."

6. Ask if the participant has any questions about the technique or if they understand. Answer any questions about how it works. Instruct them that they will be using the technique in the post-test.

7. Give roughly 10 minutes for the participant to get into the VR equipment and explore the environment. At this point, brief the participant on what controls there are on the VR controllers, and which buttons do what in the VR environment. This way when they put the headset on, they won't be searching for the buttons too much. Once within the simulation, show them how to show and hide the progress display. Instruct them to stand somewhere in the center

of the play space available to them in the real world, and try to correct their position whenever they get too close to a real wall. Have them walk around physically using the worn sensors, and collect each of the collectibles in the environment as a way to explore it (Press ‘1’ on the keyboard to initiate this phase.), using their hands without pressing any buttons. Use the training object list (Press ‘2’ on the keyboard to initiate this phase.) to have them practice selecting and placing 5 placeables before the real test. Ensure the participant knows they are not meant to memorize these training words. Let them explore if they feel the need to (within the 10 minute time limit), until they are ready for the final test. If they need more than 10 minutes for this, allow it if possible.

8. In the test, have them place several placeables and try to use the method of loci to remember all the items they place, and in what order they were placed. Tell the participant to ’try to place each item in a place in the palace that you will remember well as matching with the item. Also, make sure you pick pictures for each item that match what you think would be most memorable to you. To remember the order of the items, you can try to remember the path you took through the palace when you placed each item. If you have any spare time after placing all the items during the test, you can use that time to explore the environment and try to remember where you placed everything.”

9. When they are ready, begin the placeables (main experiment) phase. Allow them to place every object until there are none left, within the 15 minute time limit. When finished, if they have spare time, they can use this time to explore and try to remember where everything is. (Use the Unity editor to intervene if needed. Ex: Placeable gets accidentally placed somewhere wrong, you can move it to a place of the participant’s choice. Ex: Sliding a balcony’s glass to the side a little, or moving a chair out of the way to help someone get through the area successfully.)

10. When they are finished, press ‘9’ on the keyboard to save the participant’s results.

11. Next, send the participant back to the testing room, where they will write down as many of the 30 items as they can, and if possible, in the order from the palace, using the method of loci. They have 5 minutes to do this, maximum, as in the pre-test.

12. Finally, have the participant answer the questionnaire for the experiment.

Pilot-Experiment

The pilot is run the same way as the general experiment, but with 40 words in each word list.

Follow-Up

If a participant comes for a second session of the experiment, run the experiment the same way except that they do not need to answer a questionnaire when they are finished.

VR Controls:

'A' Button: Show progress menu

'Y' Button: Confirm placeable placement (Will freeze the placeable in place and generate the next image selector if there is another word to place in the word list.)

'X' Button: Return placeable to participant (So that if a glitch happens or the placeable gets thrown somewhere it can quickly be brought back.)

Middle-finger trigger/grip buttons: Press these buttons and put the correct hand next to a placeable to grab it, release button to drop the item.

Keyboard Controls:

1- Collectibles phase

2- Training placeables phase

3- Testing placeables phase

9- Save participant data

0- End current experiment phase