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WHAT MAKES A GOOD LOCATION IN THE METHOD OF LOCI: MEANINGFULNESS OF LOCATIONS AND ENVIRONMENTAL SEGREGATION STUDIED WITH VIRTUAL REALITY

Master's thesis

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What Makes a Good Location in the Method of Loci: Meaningfulness of Locations and Environmental Segregation Studied with Virtual Reality

Abstract

Method of Loci (MoL) is an efficient mnemonic strategy especially good for enhancing serial recall of auditorily presented material. MoL is traditionally used by imagining oneself on a familiar journey and associating to-be-remembered words or ideas with distinct locations on that journey. However, previous research has established that newly learned virtual environments are just as good as highly familiar environments. But much less is known about what makes a good location or an environment for the use of MoL. Immersive virtual reality (VR) headset was used in the experiment to study the characteristics of environments that affect the effectiveness of MoL. Two within-subject factors were varied: meaningfulness of locations (low - paint on the floor, high - furniture), environmental segregation (no segregation – 1 big room, with segregation – 6 small rooms). Results show that using furniture to mark locations improved memory performance. No effect of environmental segregation was found. Also, females did better than males in lenient scoring which is in line with previous research showing better object-location memory for females. Further research is required to see if the locations marked with paint on the floor are still better than controls without mnemonic training.

Keywords: method of loci, virtual reality, mnemonic strategies, artificial memory, gender

Milline on hea asukoht asukoha meetodis: asukoha tähendusrikkuse ja keskkonna liigendatuse uuring virtuaalreaalsuses

Kokkuvõte

Asukoha meetod (AM) on võimekas mälustrateegia, mis sobib eriti hästi auditiivselt esitatud materjali järjestatud õppimiseks. Tavaliselt kasutatakse asukoha meetodit nii, et kujutletakse end tuttaval teekonnal ja seostatakse meeldejäätavad sõnad või ideed teekonnal asetsevate eriliste asukohtadega. Varasemad uuringud on näidanud, et äsja õpitud virtuaalsed keskkonnad on sama head kui varasemast tuttavad keskkonnad. Palju vähem on teada selle kohta, millised asukohad või keskkonna iseärasused soodustavad asukoha meetodi kasutamist. Käesolevas töös keskendutigi selle teadmistühimiku täitmisele. Eksperimendi läbiviimiseks kasutati haaravat virtuaalreaalsust (VR). Eksperimendis kontrolliti kaht katseisikutesisest faktorit: asukoha tähendusrikkus (madal - värvilaik põrandal, kõrge - mööbliese), keskkonna liigendatus (liigenduseta - 1 suur tuba, liigendusega - 6 väikest tuba). Tulemused näitavad, et asukoha tähistamine mööbliesemega on oluliselt tulemuslikum kui asukoha tähistamine põrandalaiguga. Ruumi liigendatuse mõju mälusooritusele ei tuvastatud. Lisaks leiti, et naiste mälusooritus oli parem kui meestel, mis on kooskõlas varasemate uuringutega, mis näitavad naiste paremat asja-asukoha mälu. Edasised uuringud on vajalikud selgitamaks, kas asukoha meetodi kasutamine põrandalaiguga tähistatud asukohtadega viib parema mälusoorituseni kui see, mille saavutaks mälutreeninguta kontrollgrupp.

Märksõnad: asukoha meetod, mälupalee, virtuaalreaalsus, mnemovõtted, sugu

Introduction

Our memories define who we are. Memories guide our everyday behavior and decision-making, they help us to understand the world. Despite the recent advances in artificial intelligence research humans still easily outperform machines in dynamic natural environments. This is because humans effectively and efficiently use memories to interact with the world and with each other (Lake, Ullman, Tenenbaum, & Gershman, 2016; Stolk, Verhagen, & Toni, 2016).

As memory is essential to our lives it is understandable that much of the research is devoted to understanding the mechanisms of memory in the healthy brain. Also, as memory impairments lead to significant decrease of the life quality it is also logical that problems with memory and their neurocognitive mechanisms are in the focus of much study. However, compared to the normal memory and impaired memory relatively little contemporary research is devoted to memory enhancement.

The possibility of memory enhancement through the use of mnemonics has been known since the ancient times. One of the early triumphs of mnemonics also marks the birth of the method of loci (MoL). Yates (1966) tells a story about Simonides of Ceos, who had just left a banquet and gone out when the roof fell in killing and mutilating all of the bodies of the guests inside. Simonides could help the relatives identify the bodies as he remembered the places at which the guests had been sitting at the table. Good memory was also revered during the middle ages when mnemonic training as a part of rhetoric training was an integral part of the educational system (Carruthers, 1990). Even Francis Bacon, an empiricist and a major contributor to developing systematic observations, was a strong proponent and user of mnemonic techniques (Yates, 1966).

In this light it might even seem to be a bit surprising that there is not much research devoted to studying mnemonics. One of the most influential initial impacts on the scholarly attitudes towards mnemonics was set by Ebbinghaus whose broad aim was to adapt Fechner's pioneering methods of mental measurement to memory (Worthen & Hunt, 2011). He was interested in the development of associations uncontaminated by prior experience, which leaves little room for the use of mnemonics, whose aim is to take advantage of prior knowledge. Even though James (1981) stressed the importance of prior domain specific knowledge besides repetition in improving memory, his students like Thorndike (1905) favored Ebbinghaus' way of thinking by stating that the only sure route to learning and permanent memory is through repetition. Cognitive strategies were obviously also devalued during the behaviorist era. However, one might wonder why there is no surge of studying mnemonics in contemporary memory research? Worthen and Hunt (2011) suspect the following factors: a) conceptualizing memory as a by-product of perception and comprehension (e.g. levels of processing, Craik & Lockhart, 1972), b) perception that mnemonics artificially enhance memory with little use other than to produce gimmicky tricks of memory, c) the explosion of interest in false memory as opposed to mnemonics with its emphasis on precision and accuracy of memory.

We will next counter the first two of these arguments against studying mnemonics. Firstly, if memory was mainly just a by-product of perception and comprehension then it should not be possible to develop exceptionally good memory using strategies. That does not seem to be the case, as even though people vary in their memory performance, Ericsson (2003) has argued that exceptional memory is developed rather than born with. Some support comes from a study by Wilding and Valentine (1994) where people who made extensive use of strategies outperformed people with naturally good memory, but only in tasks where a strategy could be used (memorizing words and numbers as opposed to snow crystals). Naturals were more successful in tasks not suitable for the use of strategies. Experts and professional mnemonists such as S., Aitken and T.E. have been shown to widely use at least one mnemonic technique (Worthen & Hunt, 2010). S harnessed the power of his synesthesia, vivid multisensory imagery and method of loci (Luria, 1987), Aitken made extensive use of rhythm and organizational techniques (Worthen & Hunt, 2010) and T.E. relied heavily on mental imagery (Wilding & Valentine, 1985; also Gordon, Valentine, & Wilding, 1984).

Further evidence from fMRI studies confirms that the main difference between superior mnemonists and those of ordinary memory is not in the brain structure but in the way the brain is used. Maguire, Valentine, Wilding, and Kapur (2002) compared top performers (TP) at World Memory Championships and normal controls (NC) as to see if they differed in intellectual abilities and brain structure or activation. They concluded that TP and NC groups were not significantly different from each other in terms of intellectual ability and brain structure, but the TP group showed higher activation in regions involved in spatial memory and navigation (Maguire et al., 2002). All 10 subjects in the TP group reported using mnemonics, and nine reported using method of loci (Maguire et al., 2002). Therefore there is substantial evidence supporting the claim that using mnemonics, such as MoL, increases the memory performance of healthy adults.

The claim that mnemonics have little use other than to produce gimmicky tricks of memory is also not substantiated. Firstly, because even memorizing a list of words which can be accomplished by several different mnemonics can be used for non-trivial tasks like giving a speech or memorizing a long password. Secondly, research has shown that at least using MoL with orally presented material leads to better recall for discourses right after learning (Cornoldi & De Beni, 1991) as well as a week later (De Beni, Moe, & Cornoldi, 1997). Thirdly, especially in the educational setting, mnemonics can be combined with other learning strategies and be treated as retrieval aids rather than a core learning strategy (Putnam, 2015).

There is a variety of different mnemonic techniques. Some mnemonic techniques like MoL are general and can be used to memorize a variety of things, others (e.g. number phonetic system for numbers, keyword system for foreign words) are optimized for one type of information. MoL is often used together with other techniques. For example, three time World Memory Championship winner Ben Pridmore memorized decks of cards by combining method of loci and a technique which allowed him to form one image per two cards (Foer, 2011). MoL was chosen for the present study from amongst other mnemonics because it can be used on its own and together with other techniques, raising the potential impact of this study.

Previous Studies on the Method of loci

MoL can be taught and used in different ways. MoL usually means imagining oneself on a familiar journey, such as on a walk to work or around a house, and associating the to-be-remembered words with prominent locations of that journey. Legge and colleagues (2012) describe the MoL in the following way:

> “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.”

Even though studies have tried to understand what are the absolute necessities for the technique to work, the mechanisms of the MoL are still unclear. For example, MoL can be modified by varying the following characteristics:

- amount of training in the technique (e.g. professional, extensively trained, newly learned)
- familiarity with the environment (e.g. familiar, newly learned)
- richness of the environment (e.g. rich or poor in detail, physical or virtual)
- modality of the stimuli (e.g. auditory, visual)
- retention interval (e.g. immediate, hours or days later)
- type of memory test used (e.g. serial recall, non-serial; free recall, recognition)
- type of material to-be-remembered (e.g. list of words, key points from texts)
- participants used (e.g. healthy adults, patients with mild cognitive impairment)

Time spent on teaching the MoL is extremely varied. Some of it can be explained by the differences in the population of interest – young or old adults. It has been taught to people in up to 26 individual training sessions until participants reached a certain threshold (mean age 71.7 years; Kliegl, Smith, Baltes, 1989), two training and six adaptive practice sessions each lasting about 1-1.5 hours (Kliegl, Smith, & Baltes, 1990), three 2-hour long sessions (Moe & De Beni, 2005), 4-6 hours for older adults (mean age 69.1 years; Brooks, Friedman, & Yesavage, 1993), three 40-minute sessions (Bower & Reitman, 1972), two 1-hour long sessions (Brehmer et al., 2008), one session of training on the previous day before testing (Roediger, 1980). Briggs, Hawkins, and Crovitz (1970) even went as far as to only provide a fictional map with 20 locations on a blackboard and read preformed bizarre associations between the locations and 20 to-be-remembered nouns to participants. Average recall was 17.32 words. The current study aims to study how the characteristics of locations influence the effectiveness of MoL in a healthy young adult population and push the teaching time to be even more minimal while having the participants still form their own associations.

Usually, personal and previously familiar environments are used for MoL (Yates, 1966; Kliegl et al., 1989). But artificial environments also work. Legge and colleagues (2012) have shown that newly learned virtual environments are not worse than personal familiar environments. The participants needed to use virtual environments which they were allowed to familiarize themselves with using a monitor for up to 5 minutes, environments varied in richness

– a house, school or a warehouse was used (Legge et al., 2012). This indicates that MoL can be studied with the use of virtual environments provided by the experimenter. It has significant benefits as virtual environments can be experimentally controlled and asking the participants to create their own journey through places they are familiar with can be skipped. The author is not aware of any previous studies about the effects of MoL using immersive stereoscopic 3D virtual environments.

Some authors have noted that MoL shows superiority over cumulative verbal rehearsal for learning complicated verbal material when the material is presented orally rather than in a written form (Cornoldi & De Beni, 1991; Moe & De Beni, 2005). Others have noted that MoL is especially suitable for free serial recall tests (Kliegl et al., 1989, 1990) as the journey provides a clear linear structure for memories.

Mnemonic techniques such as MoL have been shown to lead to better memory performance with varying retention intervals, such as retrieval after 2 days when compared to maintenance rehearsal (Wang & Thomas, 2000). Another study with five participants using MoL showed that participants managed to recall on average 31.4, 34.4, 36.6 and 39.8 words out of 40 with retention intervals of 4, 3, 2 and 1 day respectively (Ross & Lawrence, 1968).

The Present Study

The present study examined some of yet unexplored characteristics of the method of loci. First we were interested in what constitutes a location in MoL. Is a location in MoL defined by a meaningful object (e.g. an armchair in the corner) or does it already work because of the spatial location itself (e.g. when marked with paint on the floor)? In the present study the subjects could use either furniture objects or colored marks on the floor as locations for MoL. The prediction is that meaningful locations here defined by furniture are superior to simple colored marks on the floor. Meaningful locations provide the subjects with more opportunity to imagine items somehow linked to or within the location. Hence we expect that meaningfulness is an important part of a location for MoL.

Second, we explored yet another factor that has not been studied in the literature of MoL. Namely, one could think that it should beneficial for MoL when the environment is segregated. In other words we asked how important is it whether the environment used for MoL is separated into compartments. In our experiment this meant that the environment used for MoL was either one big room or six small rooms. Segmenting the continuous stream of experiences into events is a fundamental property of the human mental system (e.g. Radvansky & Zacks, 2011). According to the event models (Radvansky & Zacks, 2011) the distribution of the to be memorized items across different events should result in memory facilitation (Pettijohn, Thompson, Tamplin, Krawietz, & Radvansky, 2016). Hence, it could be argued that assisting the MoL by setting some artificial boundaries into the environment – in our case separating the environment into rooms – should be beneficial for memory performance. One could argue that these artificial boundaries – in our case rooms – are indeed artificial and do not separate the continuous input stream into events. However, it has been often found that "event segmentation occurs when an event boundary is encountered, such as a person moving from one room to another" (Radvansky et al., 2011, p 1633). Both classic (Smith, 1982) and recent (Pettijohn et al., 2016) studies support that when items are learned in different rooms then they are better memorized compared to the condition when the items are all learned in the same room. Therefore, we predict that having six small rooms instead of 1 big room should aid the memorization of items.

Thirdly, we were interested in a very basic question related to the method of loci. Namely, are there any gender differences when applying this method as we could not find the answer to this fundamental question from the previous literature. Males were predicted to outperform females because of their superior spatial ability as measured with tasks requiring mental rotation of 2D and 3D objects (Linn & Petersen, 1985). Also, men made smaller errors when asked to imagine themselves in a familiar campus environment and point to the direction of other landmarks (Bryant, 1982) indicating a better sense of direction in a real world environment. However, there are conflicting findings in the literature and females have been repeatedly shown to be better at learning object-location associations (Montello, Lovelace, Golledge, & Self, 1999; Levy, Astur, Frick, 2005) just as needed for MoL. A review of these findings (Voyer, Postma, Brake, & Imperato-McGinley, 2007) concluded that "An examination of the 86 effect sizes that were relevant to object location memory revealed significant gender differences in favor of females, with a mean weighted effect size of 0.269. Thus, the present results support the notion that females have an overall advantage in tasks requiring them to memorize the location of objects." Hence we would predict that females should be better at MoL.

Hypotheses in Short

Memory performance is better in ...:

1) environments where locations are meaningful
2) segregated environments
3) female subjects

Method

Sample

Fifty seven participants (mean age 26.8, SD = 5.0, 27 females) completed the experiment. Information about the study was promoted through the mailing lists and Facebook groups of institutes of sociology, social work and social policy, computer science, linguistics of the University of Tartu. All subjects reported having normal or corrected to normal vision. Two subjects needed to remove their glasses in order to participate in the experiment. This was not considered an issue as both had minor shortsightedness (less than minus -2) and participants could go as close to objects and landmarks as they wanted. All subjects expressed their informed consent to participate in the experiment. Three participants received course credit. Six participants were removed from the dataset because: a) of not using the method of loci or the environment just learned (3), b) because of not managing to learn the environments within 3 minutes and a 30 second overtime (1), c) because of having the experience to use MoL more than 5 times before the experiment (1), or d) because of dizziness during the practice session after which she chose to cancel her participation. Final dataset contains data from 51 participants (mean age 27.2, SD = 5.1, 25 females). Highest educational level attained was as follows: 2 with at least 9 years of education, 2 with at least 12, 11 with at least some higher education, 22 with a bachelor's degree or equivalent, 14 with at least a master's degree or equivalent.

Forty participants out of 51 had no previous experience with the method of loci, 11 had used it 1-5 times. Twenty-nine participants had no previous experience with a virtual reality headset, 20 had used it 1-3 times, 2 participants 4 or more times.

The experiments were carried out in compliance with national legislation and the Declaration of Helsinki.

Stimuli

Sixty Estonian nouns were chosen for the study based on their frequency of use, length, imageability, emotional valence and arousal. Nouns were selected from the Estonian Frequency Dictionary (Kaalep & Muischnek, 2002) so they would have 3-5 letters and a cumulative sum of at least 75 occurrences in literature and journalism so no word would strike out as different (318 words). Word length was controlled to avoid the word length effect where shorter words can be rehearsed more in the phonological loop and are therefore more easily recalled (Baddeley, Thomson, & Buchanan, 1975).

Word imageability was controlled as previous research has shown that high imageability words are better recalled in MoL (Legge et al., 2012). Two raters independently rated the imageability of 318 words on an ordinal scale (low, medium, high). There was substantial inter-rater agreement between the raters, squared weights Cohen's $\kappa = 0.665$ (95% CI, .581, to .727), $p < .001$. Only the words (221) where there was a full agreement between the raters were considered for the study. Another 21 words were removed so there would be no words signifying family members, well-known Tartu's landmark names and words with double meanings.

The emotional valence and arousal was controlled because emotional words have been shown to enhance word processing speed (Kuchinke et al., 2005) and recognition memory (Kuchinke et al., 2006). Ratings of 240 words were collected on a two-dimensional scale through a web survey using Inquisit (2016) software and a code adjusted from Kolnes and Uusberg (2015). Each volunteer could either assess 66 or 80 words at a time, or choose to rate all 240 words by rerunning the web survey. Hundred and thirteen (mean age 31.26, SD = 10.28, 69 females) volunteers rated at least 66 words. All words were rated by at least 32 volunteers, and by a maximum of 52 volunteers. K-means clustering with Euclidean distance was used to group words into 4 groups by their similarity in two dimensions – emotional valence and arousal.

The same 12 of the 60 words chosen for the experiment were used in the practice session, and the same 48 formed eight word pools for the experimental session. Twelve words were presented to participants in each experimental condition from these eight word pools so that half of them would be high imageability and half low imageability words (see table 1). Words were presented in random order for each participant so that of the six low or high imageability words, two were from the first cluster, two from the second, one from the third and one from the fourth. This process ensured that the words presented as stimuli were similar in each condition.

All words used in the experiment were recorded by the experimenter (male voice) in a special recording room (T-room, n.d.) with the Speech Recorder (Draxler & Jänsch, 2016) software and presented auditorily.

Table 1

Word Pools for the Experiment

	Low Imageability	High Imageability	**Total**
Cluster 1	8 word pool (2/cond.)	8 word pool (2/cond.)	**16 word pool (4/cond.)**
Cluster 2	8 word pool (2/cond.)	8 word pool (2/cond.)	**16 word pool (4/cond.)**
Cluster 3	4 word pool (1/cond.)	4 word pool (1/cond.)	**8 word pool (2/cond.)**
Cluster 4	4 word pool (1/cond.)	4 word pool (1/cond.)	**8 word pool (2/cond.)**
Total	**24 word pool (6/cond.)**	**24 word pool (6/cond.)**	

Design

A mixed design with two within-subject variables and one between subject variable was used (see figure 1).

The first research question was: Are environments where locations are more meaningful to the test subjects better for memory recall? To answer this question, experiments were conducted in a virtual environment where the locations were marked either as paint on the floor (low meaningfulness) or with furniture (high meaningfulness). See table 2 for illustration of the subject's view. Objects used in the big room in order were: bookshelf, round table, chair, house plant, sculpture resembling the Winged Victory of Samothrace, whiteboard. Objects used in the 6 small rooms in order were: indoor palm tree, floor lamp, armchair, minimalist rectangular table, small piano, male bust.

The second research question was: Are environments where locations are segregated from each other better for memory recall? To answer this question half of the experiments were conducted in a virtual environment with 6 small rooms where the locations were segregated by walls and the participant had to move from room to room to see each location. The other half of the experiments were conducted in a virtual environment where all locations were presented in one big room. See table 2 for illustration of the subject's view.

Thirdly, we wanted to know about gender differences in the use of MoL. This was was addressed by having similar amount of males and females in the study.

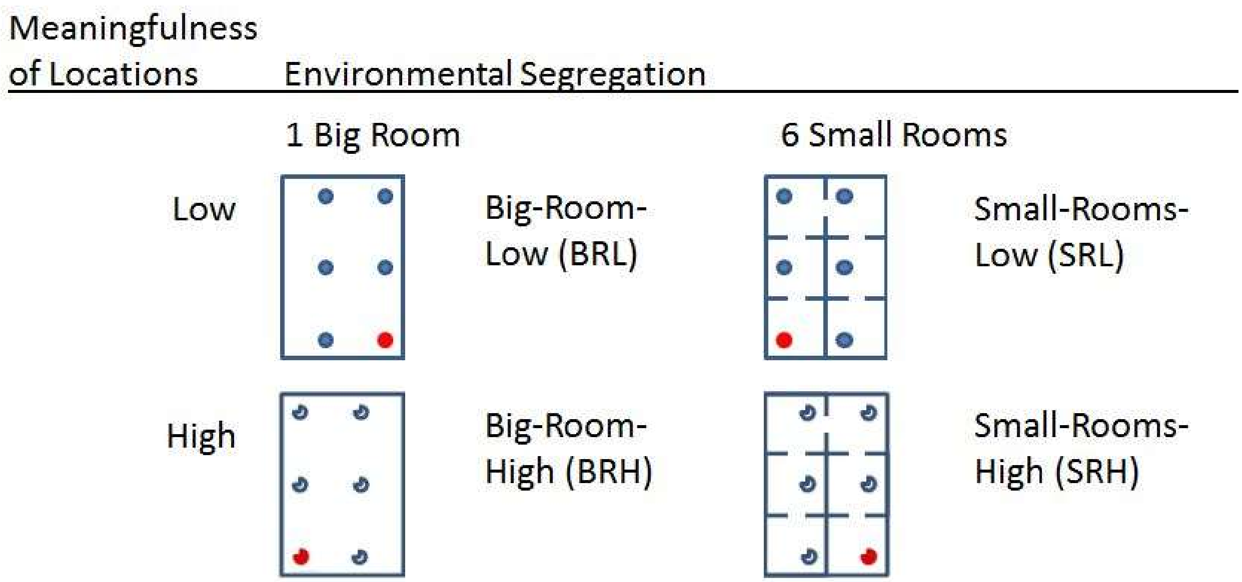

Figure 1. Experimental design for two within-subject factors: meaningfulness of locations, environmental segregation. Meaningfulness of locations: low – location indicated with paint on the floor, high – location indicated with different pieces of furniture. Environmental segregation: one big room – the whole environment is one big room where the first and last locations can be seen at the same time, six small rooms – environment with the same area as in the big room condition is split into six equally sized rooms with one location in each of them. Note that the distance travelled is the same in all conditions. Red icon on a graph indicates the first location of the environment.

Procedure

Practice Session. Method of loci was taught to participants in 15 minutes without immersive virtual reality goggles. It contained a few key instructions and an exercise to memorize 12 words by using six locations. Two words per location were used to minimize the effort of learning the environments, and because previous research by Crovitz (1971) has shown that there is no difference between the effectiveness of MoL when one or two words are associated with one location. The journey used only in the practice session was constructed by the experimenter so that it would go through six well-known landmarks in the old town of Tartu. Some landmarks were changed for some participants to assure that the journey was well-known to the participant. Participant had to briefly verbalize the journey from the first landmark to the last and to explicitly mention all the six landmarks. The participant was then asked to imagine the full journey in his/her head once again. The participant then memorized twelve practice session words presented auditorily using the method of loci with that journey. Two words had to be associated with each location, first two words in the first location etc. Word presentation speed was one word per 5 seconds.

Then, mental arithmetic was used to hinder repetition and memorizing using the auditory loop by an intermediary task, where the participant needed to count aloud downwards by 3 from 98 (98, 95, 92…) for 30 seconds. No calculation mistakes were corrected. The words needed to be recalled in their correct order (by typing the third word on the third line) in 2 minutes. Compliance was assured by asking if the participant used the method of loci and that environment for the task, or if they lost their way navigating the environment.

Participants were familiarized with the immersive virtual reality and movement keys (WASD and arrow keys) by using a small section of the Effects Cave environment (Cowley, 2014). In addition to the keyboard keys which allowed the participant to move forward, backward, sideways and turn 20 degrees at a time, participant could use his/her head to look in any direction. Moving trajectory was unconstrained. Participants were considered ready for the experiment after they demonstrated their navigation skills by crossing a narrow bridge in the Effects Cave environment.

Experimental Session. Experimental session followed the structure of the practice session (see figure 2). The order of conditions was chosen pseudo-randomly so that males and females both completed all possible 24 combinations of the conditions. On table 2 one can see all four experimental conditions from the subject's perspective.

For each condition, firstly, a top-down schematic view of the experimental environment with explanations was presented to the participant (same ones as in figure 1). Participant then had a maximum of 3 minutes to learn the experimental environment as well as possible while using a virtual reality headset. Learning was assured by asking the participant to draw the top-down schematic view of the environment without a time limit. Mistakes were corrected. Participant had the chance to see the virtual environment again until the 3 minutes was completed, or until an additional 30 seconds ran out. Most participants finished before the initial 3 minutes ran out. Participant then had to imagine going through the experimental environment once again without the VR headset so it would come effortlessly during the word learning phase.

Then, 12 words had to be learned using that environment, also, without the VR headset. An intermediary counting task followed for 30 seconds, after which the words needed to be recalled in 2 minutes. Counting task was one of the following: a) count downwards from 97 by 3, b) count downwards from 97 by 4, c) count upwards from 7 by 6, and d) count upwards from 4 by 7. These counting tasks were chosen so the difficulty would be roughly the same, and so that the counting would not match the results of the multiplication table. Counting task was included in the experiment to make the memorization task more ecologically valid, as when people learn things in their everyday lives, they usually cannot rely on rehearsing until the information is needed once again.

Three following questions were used to make sure participants followed the procedure as expected: 1) Did you use method of loci with the environment you just learned? 2) Did you remember all the locations and objects in there? 3) Did you ever lose your way? This cycle repeated until all four experimental conditions were completed (figure 2).

Table 2

First person views of experimental conditions.

Meaningfulness of Locations	Environmental Segregation	
	1 Big Room	6 Small Rooms
Low		
High		

Follow-up Questionnaire. Follow-up web-based questionnaire was sent to participants two days after the experiment. It asked for key personal details like age and education, and about previous experiences with virtual reality headsets and the use of method of loci. It also included some questions that are not in the focus of this thesis.

Technical Details

The stereoscopic 3D virtual environments were created using Unreal Engine 4.11 software. Virtual environments were presented using Oculus Rift Development Kit 2 (DK2) virtual reality headset with a low persistence OLED display, 100 degree field of view, 75hz refresh rate and 960 x 1080 pixel resolution per eye. The system was running on a PC with Intel Core i74970K, MSI GeForce GTX 970 OC and 8GB of RAM.

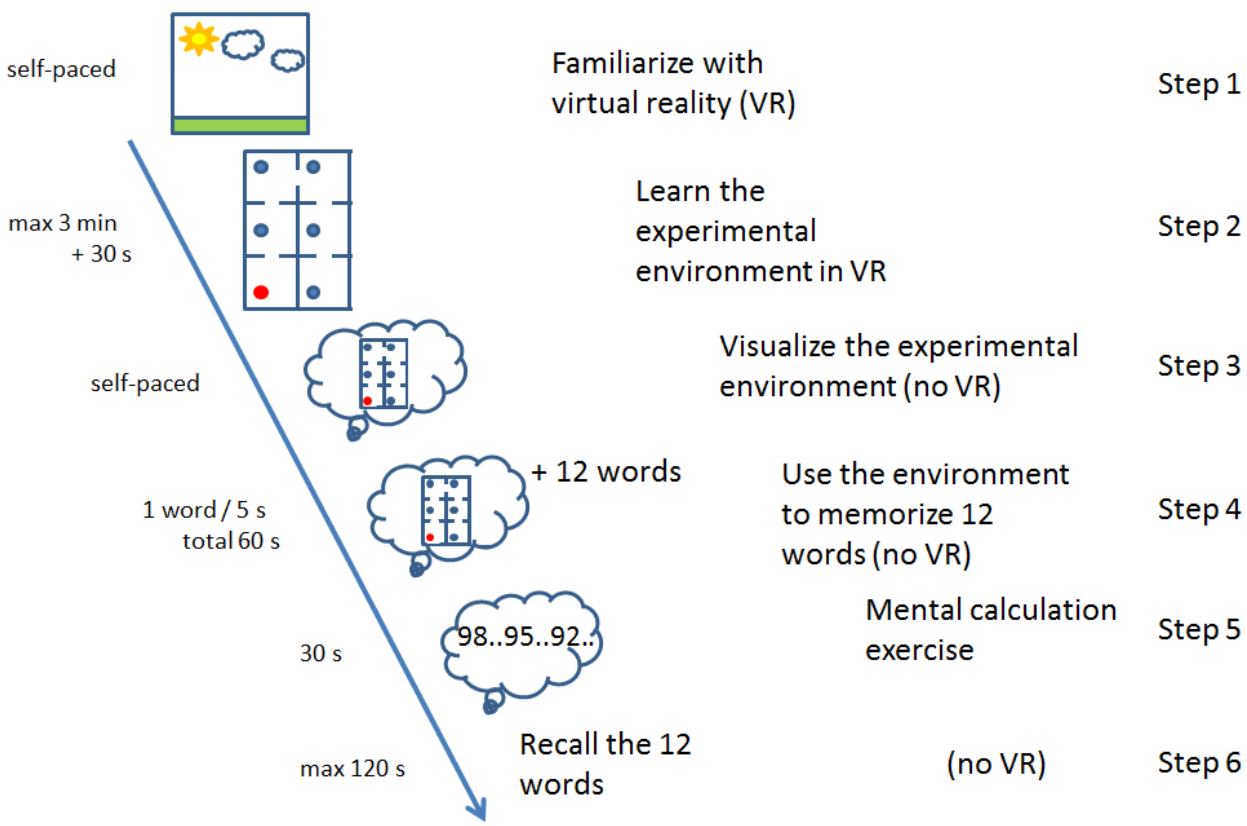

Figure 2. Experimental process. Participant is first familiarized with virtual reality environments in general. Steps 2 to 6 are repeated until a participant has completed all four experimental conditions.

Statistical Analyses

Statistical analyses were performed using IBM Statistical Package for Social Sciences version 24 and R version 3.2.4. Recall was scored by both a lenient criterion (credit given for a correct word recalled and written in any line) and a strict criterion (credit given only when a word was recalled and written in the correct line). Mixed design ANOVA with meaningfulness of locations and environmental segregation as within-subject variables and gender as between-subject variable was carried out to test the hypotheses. ANOVA was used even though Shapiro-Wilk's normality test revealed that the assumption of normality was violated in several conditions with lenient and strict scoring, because ANOVA is considered robust against the violations of that assumption (Schmider, Ziegler, Danay, Beyer, & Bühner, 2010). Brown-Forsythe Levene test based on the absolute deviations from the median confirmed that the assumption of homogeneity of variances was met for all variables with lenient scoring, and for all within-subject variables, but not for the between-subject variable with strict scoring. Brown-Forsythe Levene test was chosen because it is more robust with non-normally distributed data. The assumption of sphericity could not be violated as none of the variables had more than two levels.

Results

Similarity of samples of males and females was tested using Mann-Whitney U tests. They showed no statistically significant differences between the ages (U = 338, p = .813), educational attainment (U = 239.5, p = .089), previous experience with MoL (U = 340, p = .692) and immersive virtual reality (U = 304, p = .657) of males and females.

Two-way mixed design ANOVA was conducted for free recall (lenient scoring) results (Figure 3 top row). There was no statistically significant interaction between the effects of gender, meaningfulness of locations and environmental segregation, $F(1, 49) = .122$, $p = .729$, nor between any combination of two variables. However, a statistically significant effect was found for gender, $F(1, 49) = 4.283$, $p = .044$, $\eta_p^2 = .080$, showing that females did better than males. A second statistically significant effect was found for the meaningfulness of location, $F(1,49) = 30.997$, $p < .001$, $\eta_p^2 = .387$, meaning that more words were remembered when they were associated with objects rather than ink on the floor. There was no main effect of environmental segregation, $F(1, 49) = 1.761$, $p = .191$.

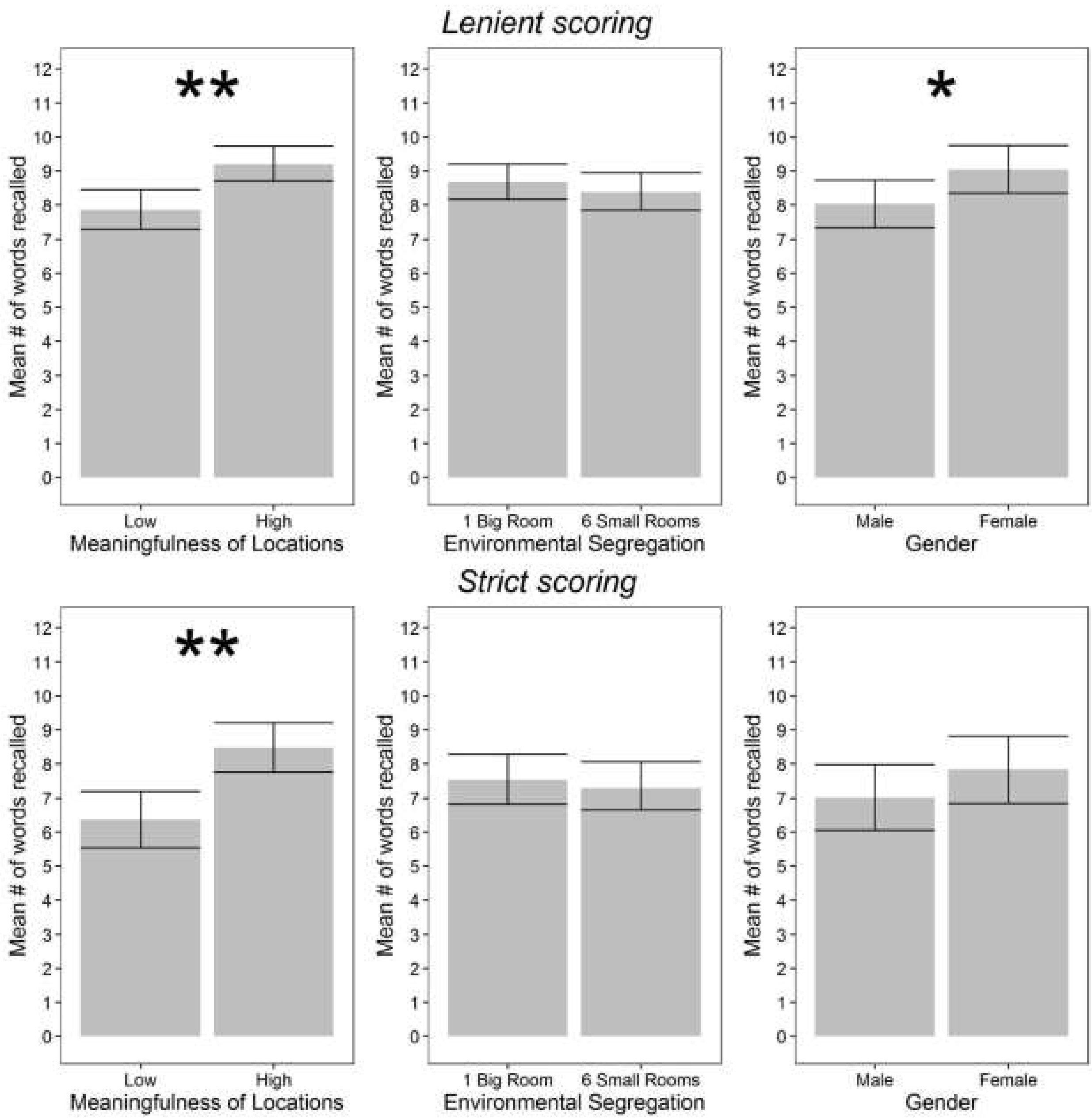

Figure 3. Mean number of words recalled. Top panel shows the means with 95% confidence intervals for lenient scoring, bottom row for strict scoring. * $p < .05$; ** $p < .001$.

Mixed design repeated measures ANOVA with meaningfulness of locations and environmental segregation as within-subject variables and gender as between subject variable was conducted for free recall (strict scoring) results (Figure 3 bottom row). No statistically significant interaction was detected. However, one main effect of meaningfulness of locations was found, $F(1, 49) = 33.184$, $p < .001$, $\eta_p^2 = .404$ indicating that associating words with objects compared to ink on the floor leads to better ordered recall.

Discussion

Flexible use of memories is crucial for human-level intelligence. There are many open basic questions about how memory works in the healthy brain. One fundamental question that has been relatively neglected in the contemporary memory research is how the normal memory can be improved. There are many well-known methods for memory improvement, i.e. mnemonics, but the basic cognitive mechanisms underlying these methods have not been the subject of thorough investigation. Here we studied one of the most well-known mnemonics**,** method of loci (MoL) and investigated what constitutes a good location for MoL. We studied the effects of meaningfulness of locations and environmental segregation on MoL with the help of immersive virtual reality goggles**.** The main finding of this study is that meaningful locations (furniture) in MoL lead to better memory performance compared to non-meaningful locations (black ink on the floor). No statistically significant effect of environmental segregation was found. We next discuss these findings, address limitations of the current study and finally provide ideas for further studies.

Meaningfulness of Locations

The method of loci is heavily dependent on the locations used for memorizing the items. However, it is unknown what actually constitutes a location for MoL. Intuitively it seems that a to-be-remembered word or an idea can be associated more easily with locations marked by an object or a constellation of objects. However, maybe it is enough when the location is just marked by black ink on the floor. In the present study we observed that when meaningful objects are used for location then memory recall is better compared to that condition where black ink on the floor are used. However, the benefit of having furniture compared to ink marks was not big: 1.3 items with lenient scoring and 2.1 items with strict scoring. A limitation of the present studies is that we did not use a baseline condition, i.e. a condition without any locations, or without any mnemonic training. Hence, we actually cannot say whether the ink on the floor was already beneficial compared to no locations, or compared to no mnemonic training group scores. It must also be acknowledged that we actually cannot be sure that the present effect is an effect of meaningfulness of objects. As the comparison condition were marks of black ink on the floor then maybe to benefit was not from meaningful objects but simply from having objects. An important future comparison would be between meaningful and meaningless objects.

Effect of the Environmental Segregation

Segmenting the continuous stream of experiences into events is crucial for understanding the world (Radvansky et al., 2011). It has been found that segregating the environment with boundaries is beneficial for memory performance (Pettijohn et al., 2016). However, in the present study we were unable to find any effect of environmental segregation**.** Subjects were generally not better at recall when the environment consisted of six different smaller rooms instead of one big room. There are many possible reasons for this negative finding. First, maybe the study set – 12 words - was not large enough for the environmental segregation to take its effect. Second, maybe the effect of the environmental segregation would be apparent when there would be more than 2 words per room. Third, it is also important to note that these two conditions - one big room and 6 small rooms – were different in several key aspects. Our intended manipulation was to have environmental segregation, however having walls in the condition with 6 small rooms also meant that the subjects in this condition could not see all the other objects at the same time during training. In other words when there is only one room then all the 6 objects in the environment are visible and subjects could perceive and memorize the general layout of the environment better. Also, it was more difficult to rehearse previous objects in six small rooms as one needed to walk back a few rooms compared to just turning one's head in one big room. In addition, when the subjects are in the test phase it might be simply harder to imagine the environment with 6 small rooms because then additional mental resources are needed to represent the rooms and the walls. Hence, it might be harder to apply the environment with 6 small rooms for using MoL. This effect might cancel out any potential beneficial effect of the environmental segregation. Therefore, to clarify the effect of environmental segregation for MoL, the next experiments should use a longer training phase so the use of the segregated and not segregated environments would be more automatic.

Effect of Gender

In our study females achieved higher memory performance than males. This result is in accordance with previous studies finding that females are better at learning object location associations (Montello, Lovelace, Golledge, & Self, 1999; Levy, Astur, Frick, 2005). However, there are crucial limitations of the current study which makes the author cautious against strong claims. Even though there was no statistically significant difference in ages, educational attainment, previous experience with MoL and immersive virtual reality between males and females, there are artefacts that might be other factors responsible for the effect. For example, there are gender differences between auditory information processing. Schirmer and Kotz (2003) found that women distinguish prosodic information faster than men and integrate that information into word processing even when it is task irrelevant. Another study by Schirmer, Kotz, and Friederici (2002) found that females integrated prosodic information earlier into word processing and did that even when the prosodic information was not attended to. Word recall was also better for females who listened to male voice expressing words with neutral emotional prosody compared to males listening to males (Yang, Yang, & Park, 2013). In other words it may well be that some unspecific difference between the groups was the driving force of the male female difference observed in the present study.

Limits of the Present Study

Despite being seemingly straightforward MoL is actually a rather complicated method. One must be able to imagine oneself on a route, choose which locations to use and then imagine the to-be-remembered item there as well. Therefore, people with greater aptitude could benefit more from the strategy. Wang (1983) found faster learners could generate more associations with the same time as slow learners, and their elaboration was more effective even when they used the same elaborative strategy.

In the present study the subjects also had to visualize an environment that was just learned and then actively place items into that environment. In other words they were actively holding in their working memory the to-be-remembered item and the newly learned environment. Hence one might predict that if the subjects would have used already familiar environment as the environment in the MoL then they would have performed even better than in the current experiment. However, one of the goals of this study was to use virtual reality together with a very short training time for MoL. Also, previous research has observed that under some circumstances using non-immersive virtual reality (desktop display) training with new environments can be as beneficial for MoL as using a familiar environment (Legge et al., 2012).

One of the key limitations of this study was the ceiling effect, which occurred 22 times out of 204 trials with lenient scoring, and 20 times out of 204 with strict scoring. This raises the probability of a type II error, as the full extent of variance that the factors could have caused was not in the range of the measure. Future research with similar designs could make the task harder by adding more rooms or locations (9 rooms instead of 6, 2 locations per room instead of 1), by using a longer or more complex intermediary (1-2 minutes instead of 30 seconds, random calculations including addition, subtraction, multiplication and division).

This experiment was optimized to study the relative difference between two environmental factors that might influence the effectiveness of MoL. Therefore a control group with no mnemonic training was not necessary. Although a control group like that would help to answer the question whether MoL with low meaningfulness locations is already better than a strategy without MoL.

Yet another possible interference was introduced by associating two words or ideas per location. There were six high imageability and six low imageability words per condition, but their order was fully randomized. It means that it was possible that a high imageability word was presented as a first word in a location marked by ink on the floor, and therefore started to act like a meaningful location for the next word.

Throughout the last two millennia the method of loci has been successfully applied by both laymen and scientists. Hence, unlike in the case of many other psychological phenomena we know that the effect is real: MoL helps to improve memory in both young and old, in healthy and in cognitively impaired subjects. It is unfortunate that this effect has not been a target of much rigorous scientific study. While there are a number of studies that have investigated the different factors that affect the practical use of MoL (reviewed in the introduction), relatively little is known about the basic mechanisms underlying MoL. What are the minimal ingredients that make this method so successful? It seems right now that there are three basic ingredients: 1) the environment has to be visual, 2) there have to be locations defined by (meaningful) objects, 3) the locations have to be serially ordered. But actual research showing that these are the three basic ingredients is lacking. For example one question that came up during the present study was whether locations could simply be colored marks on the floor. An even more basic question is whether a visual environment is needed at all or whether a series of visual images could also act as basis of the “journey”.

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Competing Interests Statement

The author declares that he has no competing financial interests.

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