Importance of personal investment for creating representations of the elements-to-be-remembered with the method of loci in virtual reality

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***Abstract*— The Method of Loci (MoL) is a powerful mnemonic technique that has been used for centuries. The capabilities and the usefulness of this technique lead to advanced memory recall for the ones who use it. Due to the fact that this method is based on mental representations of the world, several researchers found an interest in connecting it to the current Virtual Reality innovations. The different studies present a relevant usage of these technologies to learn, use, or enhance the MoL. Nonetheless, there is a lot of open-ended questions, this paper will focus on the importance of personal investment in the context of the VML (Virtual Method of Loci).**

This manuscript takes place in the context of the final year of Computer Science Engineering degree in the Polytechnic School of the University of Nantes. However, this paper is not a master thesis due to the time allocated to its conception.

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CONTENTS

I. Introduction

A. Method of loci

The MoL, also named "memory palace" or "mind palace", has for fundamental property the visualisation of a specific known environment where a list of elements will be remembered. The concept and the exploitation of this method can seem pretty simple but although can require a lot of concentration, creativity and practice depending on the user ability. [Brooks et al.1993] showed that a training period of about 4h to 6h was necessary before the technique becomes effective.

To use this method, the user must first visualise a known environment in which they will move through a specific path. It can be their house, their work-space, or even the commute to their office. Once chosen, the user will travel in this environment and place the different elements that need to be remembered in the different locations (*in Latin: Loci*). To retrieve later the list of items, they will only need to "walk" again in the same imaginary environment with the same path and see the different items.

Depending on the nature of the element to be memorized, different versions of the MoL can be applied. If the information to be store is unlinked (e.g. a list of animals) a variant is the "Roman Room", in this version there is no precise path in the imaginary environment, but still a set of elements placed in the environment. The most popular version of the MoL might be the "Journey Method", as presented in the previous paragraph, there is a precise path in which the user navigates. This version allows remembering long lists of related information (e.g. list of events by date, the more the user is advancing the more recent the event is).

Another important aspect is the imaginary representation of the information. Some items can be really tough to represent. For example, if its acronyms, we can replace each letter by a word (e.g. guitar strings A D G B E: Archers Dog Grass Bee Explorers). But for some complex word or concepts like Vestibulocochlear (if you want to remember cranial nerves), you need to imagine an item or a list of items that will be sufficient to recall the original word.

Some completing strategy exist depending on the context. If you want to remember a list of numbers you can learn an equivalence between a part of the alphabet and the 10 digits (0 to 9, for example, 3 can be m, 8 can be f and so on). Then split the number into groups of digits, translate the groups in acronyms and finally in items. With this kind of technique, Gary Shang memorised pi to over 65 536 digits.

Another presentation of the instruction of the MOL from [Legge et al.2012] can be seen in the Appendix of this paper.

B. Historical background

1) Antiquity: . In the Antiquity, the subject of memory was really important. Its history start with the Greeks. They invented many arts, and one of these arts was the "art of memory". So memory has a real place in their lives.

A lot of Greeks mused about the memory and it's really hard to explain all the way of reflection of the Greeks, the best way to understand the different point of view of the Greeks may be to read the "Art of Memory" [A. Yates1984]. To make a simple overview, the Greeks distinguish this art in two kinds of artificial memory, memory for things and memory for words. But both memory need images to represent what you want to memorize. The images are in the center of the art of memory. For example in *De anima* Aristotle say 'it is possible to put things before our eyes just as those do who invent mnemonics and construct images' and for him, it is impossible to think without a mental picture is constantly brought in to support the use of images in mnemonics. Like all the Greeks arts, this art was

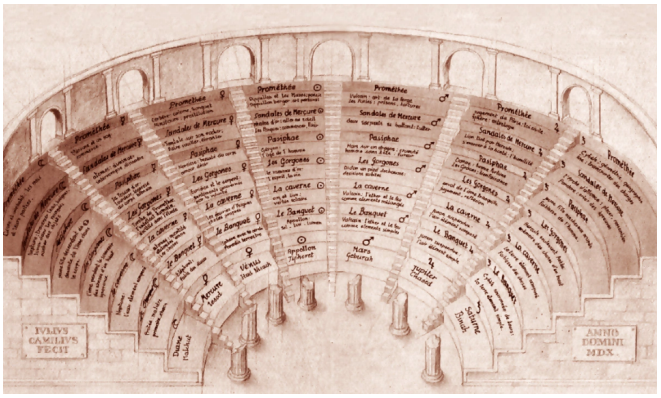

Fig. 1. Representation of a memory palace by Giulio Camillo (1511)

passed to Rome and the European tradition.

2) Middle ages: After the antiquity and all the Greeks's studies, Rome passed this art of memory to the European tradition.

During the middle ages, there is two main epoch for the art of memory. The first one is during the early of these ages. It was the barbarised world and it was really hard to share the knowledge. During this period

the art of memory becomes unnecessary and only used in monasteries (except for the memorizing of a prepared written page). An important moment during this period, was when Charlemagne call Alcuin for help to restore the educational system :

Tullius explain that we need to follow four-point to

Charlemagne. What, now, are you to say about Memory, which I deem to be the noblest part of rhetoric ?

Alcuin. What indeed unless I repeat the words of Marcus Tullius that 'Memory is the treasure-house of all things and unless it is made custodian of the thought-out things and words, we know that all the other parts of the orator, however distinguished they may be, will come to nothing'.

Charlemagne. Are there not other precepts which tell us how it can be obtained or increased.

Alcuin. We have no other precepts about it, except exercise in memorising, practice in writing, application to study, and the avoidance of drunkenness which does the greatest possible injury to all good studies...[5]

Fig. 2. The dialog of Charlemagne and Alcuin

well memorise. These four points are the same as the points of the MoL, similitudes of the things which he wishes to remember, place in a considered order those things, use of personal emotion and perception to appropriate this list, meditate frequently (work this memory).

The second period is when the printing press was created. Combined with the educational system, the knowledge and the sharing of knowledge evolved. With this innovation knowledge spread across the medieval civilisation and ended the middle age. Books which talk about the art of memory were printed which renew the practice of this technique.

3) Renaissance: Giulio Camillo Delminio, was an Italian philosopher of the Renaissance, during the sixteenth century. Financed by the King of France, this person created a mysterious Theatre, no one knew what was this Theatre for but it was seen in Venice and later in Paris. It was found that this theatre represented a new physical way to envision the Method of Loci. It aimed to represent the history of memory during the Renaissance and became the *Memory Theater*. (See "Art of Memory" of [A. Yates1984] Chapter "The memory theatre of Giulio Camillo").

4) Contemporary Period:

Memory contests: Memory contests are a new contemporary way to challenge our memorisation. In these contests, contestants try to remember a large amount of information like number, card, or others. These persons have really impressive memorisation capacity and elaborated methodologies. Such as the method of loci, that's the proof of the efficiency of this method. This affirmation is well explained in this citation: "The MOL is still one of the most utilized strategies for world-class mnemonists trying to remember exceptionally large amounts of information quickly" [Legge et al.2012].

Studies: The MoL isn't used for studies in general, but it is easy to imagine the power of this method for educational purpose. Some persons try to inculcate this method for their student, for example for the future doctors. There is a lot of situations like this. In the case of [Qureshi et al.2014], the method of loci was used by a group of student, and the other group don't use it. With this technique they can know if the method of loci is really useful, and if we can use this method in the context of education. The students were taught insulin and diabetes mellitus through didactic lectures, but one group memorise this course with MoL and the other one with his proper technique. The result is glaring, in this MCQ the mean for users of MoL is 9.31, against 8.10 for the other group. After that, they did a questionnaire to know the view of the students.

This article is also interesting because it shows some

	Strongly Agree		Agree		Neutral		Disagree		Strongly Disagree		Missing System	
Item	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
1. MOL was a very helpful technique.	13	46.4	15	53.6	0	0	0	0	0	0	0	0
2. I was able to recall the facts better after learning them with MOL.	14	50	12	42.9	1	3.6	1	3.6	0	0	0	0
3. MOL helped me understand the topic better.	11	39.3	13	46.4	4	14.3	0	0	0	0	0	0
4. I learned more during the session with MOL compared with my previous experience in physiology.	11	39.3	9	32.1	5	17.9	3	10.7	0	0	0	0
5. I would like to continue using MOL to learn more topics in physiology.	13	46.4	12	42.9	1	3.6	1	3.6	1	3.6	0	0
6. I would like to continue using MOL to learn other subjects as well.	12	42.9	10	35.7	3	10.7	2	7.1	1	3.6	0	0
7. I was more comfortable with MOL because it was being taught by students themselves.	8	28.6	10	35.7	6	21.4	4	14.3	0	0	0	0
8. I performed better on my assessments on topics that I learned using MOL.	10	35.7	14	50	3	10.7	1	3.6	0	0	0	0
9. I would like to share the MOL technique with friends and family.	15	53.6	9	32.1	4	14.3	0	0	0	0	0	0

Fig. 3. Results of the questionnaire analysing students opinion[Qureshi et al.2014]

problems with the MoL. Mainly the difficulty to learn this method, in this case, the student had a course of MoL, to know how to use it.

Medical purpose: Today some researchers work on the effect of memory method like MoL for patients

who have a memory impairment. These different experimentations show a lot of possibility for MoL. For example, [Richardson1995] explain it depend on the disease the education, the imagery abilities and other points, but for him, this technique aren't really useful for the cognitive challenge of everyday life. Despite everything the method of loci is probably helpful for some patient like explain in this citation : "the MOL has been investigated, with some success, as a possible aid for memory-impaired individuals ([Richardson1995]; [TATE1997]) and to address memory decline in healthy ageing adults [Hill et al.1988]."

C. Cognitive Psychology bases

1) Introduction to the types of memories: Our individual memory is split into two main components, the short-term and the long-term memory. The first is responsible for holding a small amount of information (in average 7, plus or minus 2) for a quick amount of time. The second one aims, as its name indicate, to store information for a long time. Long-term memory is itself split in two-part, the implicit memory which is responsible for information that is learnt and reinforced unconsciously (a great example is the priming technique, we can improve the performance of a subject by subconsciously preparing them). The second long-term memory is the explicit memory, which the MoL play an important role as explained in the next section.

One last time, we can divide explicit memory into two categories, the episodic memory (autobiographical) which store personal experiences and the semantic memory which store factual information.

There is also the spatial memory that is responsible for recording information about environments and spatial orientations. This memory has representations in both short-term and long-term memory. This section is voluntary simplistic as there is a lot of theories, abstractions and concepts linked to memory as there is still debates around these elements in the community or there are too specific and not enough relevant for this paper.

2) MoL's performances explanation: Various are the arguments that explain the performance of the Method of loci. One of the most important reasons why this mnemonic technique work is the usage of the spatial process. Since the 1970s a lot of studies has shown a relation between spatial navigation and information recall. Evolutionary theories posit the creation of a mind was to engage in purposeful movement. Which, in a first time, provided an advantage in navigation by generating a cognitive map [Murray et al.2017] (e.g. avoid dangerous areas, harvest resources, find water...). The spatial aspect is so important for the encoding of the information that it seems inevitable to envision autobiographical memory without any spatiotemporal context ([Moscovitch et al.2016], [Tulving2002]). This spatial information aspect takes another primary advantage as it is often the earliest information recalled in the retrieval process([Hebscher et al.2017]). As proof of its extension to abstract concepts, ([Benn et al.2015]) showed that navigation through digital folders activated the same areas used in the real-world navigation. [Constantinescu et al.2016] demonstrated in more detail to the notion that spatial processes are used for the encoding of information. This is why the spatial reasoning involved in the MoL is primary to the benefits of this method. Proof of these benefits on the MoL, a study of [Fellner et al.2016], show that memory champions(compared to a study group) disproportionately recruited areas of the brains (posterior hippocampal and medial parietal lobe regions) known for supporting the spatial memory.

Many other elements of the MoL explains its performances. One of them can be the self-reference effect, the usage of personal meaning in the information[Symons and Johnson1997]. As the information is learned from the first-person point of view, the autobiographical process could be used, as this process engages more regions that the non-autobiographical tasks[Chen et al.2016], it could improve the performances. The emotional contexts of the palace can also increase the memory encoding and consolidation, as the review of [Hamann2001] show that emotional arousal enhances the explicit memory. Another argument is the time spent on visually elaborating the information and contemplating the to-be-remembered object which could harness the long-term working memory[Ericsson and Kintsch1995].

II. Fields of research and Related Work

A. Introduction

1) Virtual environments: In our context, virtual environments(VEs) represent a system aiming to simulate our real-world environment. It can consider perspective, gravity, lights, any aspect of our physical world and his displayed through a monitor or a stereoscopic device(see next section).

Hardware for VE: One of the first technologies of the early stages of computer science used to display VEs is obviously the monitor. Starting with the CRT(cathode-ray tube), then the liquid crystal display(LCD) this technology allow to render visual content through a 2D screen. Monitors present a lot of advantages, cheap price, wide usage, compatibility... But it lack essential features for a perfect immersion in a virtual environment, like stereoscopy, a wider field of view.

CAVE (Cave Automatic Virtual Environment) system is an attempt to solve these problems and increase the immensity of the virtual environments. This system is composed of several projectors that display the VE in high-resolution on three to six walls. The user generally wears 3D glasses inside the CAVE, allowing them to see 3D effects. The last emerging

Fig. 4. A CAVE environment used for flight simulations.

technology used for displaying a virtual environment is the Head-Mounted Display(HMD) (Review in [Rolland and Hua2005]). This device is composed of one or several images sources collimating optics allowing effective render of stereoscopic images. Although being developed and used since the 60s, for military purpose in first case, this kind of device has known democratization since 2012 through the gaming industry with the virtual reality headsets, Oculus Rift. Many VR headsets have followed in the past few years, allowing the usage of these devices to a wider population.

All these technologies, depending on the user, can have secondary effects like nausea, oculomotor and disorientation symptoms. For a review of these side effects see [Sharples et al.2008].

Fig. 5. A virtual reality HMD which has the particularity of using a smartphone as primary screen.

Software: Depending on the wanted property, building a virtual environment can be an extremely complex task. So many functionalities need to be developed like cameras, graphics (2D or 3D) textures, physics, events and so on... This is why nowadays, popular game engines(which are IDEs) are used for creating Virtual Environment (often in the context of game development). These IDEs has generally an extensive API with various modules and features. We will focus on the two most popular game engine Unity and Unreal Engine.

Unityis the most popular VR engines in terms of usage. You can create 2D or 3D applications and it supports C, unityscript and Boo. Unity is free to use, it relies on a SAAS business model with an online Asset Store and some royalty fees for professional users.

Unreal Engine was created by Epic Games and a lot of popular games have been developed with, this engine is the best for graphics and details. It supports only C++. Unreal is more professional and more expensive than its competitor. Moreover Unreal has some problems for VR (graphical problem) like in No Man's Sky.

These engines have a lot of models that can be used by developers for basic things, like a chair for example. These banks are very helpful to develop some prototype or game quickly without worrying about the different assets.

2) Objectives and systems:

Explanation of the interest of VEs for the MoL: VEs has a real interest for the MoL. The different articles about MoL with VE through VR testifies this interest.

The VE in VR is really the best way to have a tangible representation of an imaginative world. And that's the reason why a lot of people want to use VR for MoL and for a lot of others uses. This point is really important because it's the main reason for the creation of this article, create a tangible palace for the MoL.

But it's also a way of solving some problems :

- The first problem of the MoL is the time to learn this method, so we can imagine a VR application to help users to learn MoL, helped by visual elements.
- Another problem is the difficulty of some people to imagine an imaginary space. It is necessary to have creativity and imagination to create a palace, and to help the person who doesn't have a lot of imagination, we can imagine a VR application for creating a palace. In this palace, we can help the users to place what they want to remember.
- For some persons, it's hard to travel in an imaginative place, so in a VR application, the person can really travel in this place. We can add real movement or interaction which can increase the helpfulness of this technique for remembering(see the State of the Art part).
- Thanks to this numeric environment, it is easier for researchers to analyse the effect of the method of loci because the experiment can be controlled in an advanced way.

All these solutions can help with using the MoL or replace the imaginative part of the MoL. But it's important to remember the importance of the feeling with the place and the object and the importance of the interactive part. So we need an ergonomic application with a place really famous or create by the users himself.

Software for the use of MoL through VEs: Some people have done software for the VML(Virtual MOL). Like Munx VR, created by Dr Aaron Ralby, a linguist and expert in memory training. The objective of Munx VR is to create a platform for building memory palaces in 3D. This palace aims to help, for example, a person to learn a language in a short time. This app has 3 different modes:

- Free build, in which the user can create and manipulate mnemonics in the space. He can also change the size of the palace.
- Guided build, in this one Munx offers some modules to create a palace for a type of information, for example for a language.
- Instructor mode, to create this module (for teachers for example).

This project was made in Unity. Another project is *Link In Your Mind*, in this one the users can create a mind map he wants to learn, but in 3D. He can move this in the space. It's a VR environment or an AR (with Hololens) and the interaction is created with remote (HTC Vive) or with an eyes focus (Hololens). The last project is Immerse Your Brain. In this project, the MoL is used to learn lessons, like another language. In this case, it's a 360 video interactive. The users can see in the direction of items and see different translation.

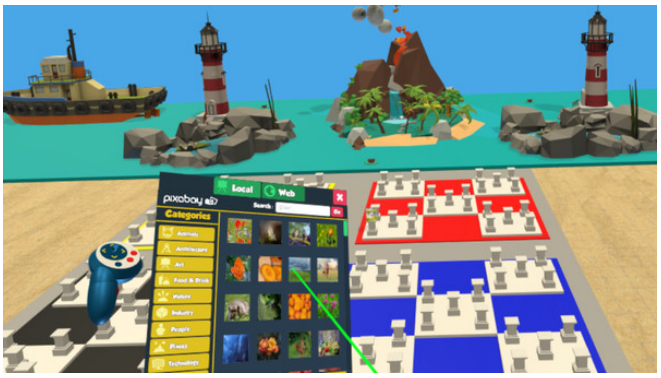

Fig. 6. Munx VR, building mode.

B. Scientific State of the Art

As said previously there is an interest in using the method of loci in virtual reality. The following sections review the current state of the art of this domain through different aspects that has been studied by different researchers.

1) Impact of the hardware on the performance of the MoL: Probably the most important question in this domain is the impact of the technology on the performances and the usage of the MoL. [Mann et al.2017] put this problem as two driving questions: "Does the sense of spatial navigation generated by an immersive virtual experience aid in memory formation? Does virtual spatial navigation, when paired with learning cues, enhance information encoding relative to nonspatial and nonvirtual processes?". This is primordial as it directly defines the relevancy of the usage of VR for using the MoL. Several studies analyze this impact, depending on the device, mostly on neophyte participants.

[Fassbender and Heiden2006] were the first to compare the impact of the VML, their result showed better results for the users of VR but the number of participants wasn't enough important. [Cho2018] made the first large scale comparison and showed promising results for this field. In this study, 142 participants were assigned in three groups:

- cMOL, participants who use the MOL in a familiar environment
- vMOL, participants who use the MOL after interacting with an unfamiliar virtual environment

- CON, a control group of uninstructed participants that used a re-call strategy.

The objective for the participants was to learn 10 lists of 11 unrelated words. The specificity of this study is that the system for the vMOL group just aimed to show an empty environment. Nevertheless, results showed that the cMOL and vMOL group had similar results, proving that recalled virtual environment worked for using the MOL.

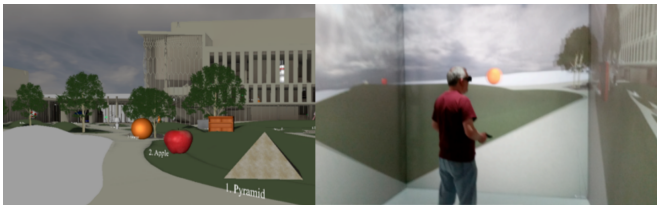

Fig. 7. Usage of CAVE for the MOL [Mann et al.2017]

Following this study of Legge et al., several groups of searchers analyzed the importance of immersion in the virtual environment by comparing the different possible devices.

There is often two different kinds of score. The Strict

TABLE I
DEVICES OR METHODS USED

Studies	Basic Re-Call	Mental MOL	Desktop	CAVE	HMD
Fassbender and Heiden	x		x		
Legge et al.	x	x	x		
Huttner and Robra-Bissantz			x		x
Krokos et al.			x		x
Mann et al.	x	x	x	x	
Yeonhee Cho			x		x

Score which aims to see is the user remembers the elements in the correct order or the Lenient Score that compares the overall re-call of elements disregarding the position.

One main output appears whether the Strict or Lenient is compared, the more immersive the learning is, the better are the performances. [Huttner and Robra-Bissantz2017], [Krokos et al.2018], [Cho2018], all the results of these studies demonstrate with more or less statistically significance the benefits of immersion (8.8% for [Krokos et al.2018], 5 to 7% for [Huttner and Robra-Bissantz2017]). The main reason is that, compared to desktop displays, Virtual Reality displays give a superior spatial awareness by leveraging our vestibular and proprioceptive senses. This difference could also be an impact of the motivation (see the third section).

2) Impact of the design and interaction with the palace on the performances: Each of the studies has a different way to implement the MOL in a virtual environment. The implementation itself is really an open-ended problem due to the limitlessness of VR and the possible interpretations of the Method Of Loci. Another challenge is the embodiment[1] and the assimilation of this environment by the user.

Most of the studies don't aim to create an absolutely perfect experience of the MOL, but rather analyze one particular aspect(e.g. the device in the previous section). Thereby, some features are sometimes avoided, or some aspects of the MOL are simplified to emphasize on the aspect to be analyzed. You can see two different table reviewing the features of the experiment that have been done in Appendix II.

Concerning the palace, most of the studies use an imaginary virtual environment. A space that is made up but, but which has often a realistic meaning like a classroom, a museum, a castle... Which shouldn't matter if we take note of the result of Legge et al., which shows that usage of a familiar or recently learned environment doesn't make a difference. Nevertheless, we can remark the study of [Mann et al.2017] that used a realistic virtual environment of the Virginia State University(where this study has been conducted). [Kivisik2016] is the only study(Master thesis) that analyzes the impact of the palace. Two main factors where varied: the meaningfulness of the palace and its segregation.

The first one can be varied by having or not furniture, the second aspect vary from one big room or six little ones. As [Legge et al.2012], this study use an "External MOL"(see II). Which mean in this context that the elements to be-remembered are not in the environment. The palace is just a support for the usage of the MOL. Long story short, results show that meaningfulness improved memory performance but no

[1]Embodied cognition https://en.wikipedia.org/wiki/Embodied_cognition

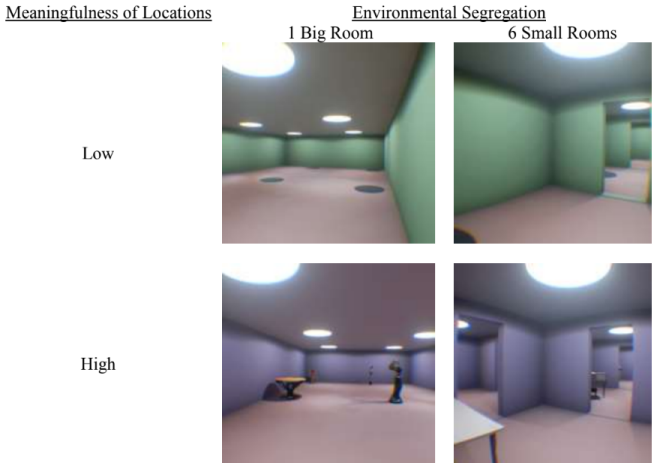

Fig. 8. The different variation of environment in [Kivisik2016].

effect of segregation was found.

Concerning the element to be remembered, there is a lot of variation as you can see in II. It can be either text, images, 3D elements, or even a combination of these forms (e.g. the Memory Cube, which is a cube with an image on each of its faces**??**). [Huttner et al.2018] compared for example one version where the content to be recalled is images associated with text and the other one is text-only. Interestingly, the lenient scores improved by 11% with the images.

Objects are mostly placed arbitrarily by the researchers in the non-external MOL studies. Which is pretty disquieting as placing the elements is one of the primary aspects of the traditional MOL. [Reggente et al.2019], analyzed this particular aspect by allowing or not the user to place the elements. Despite similar engagement and exposure duration, the results show an improvement of the recalled objects by 28%.

3) Importance of spatial ability: Spatial ability is the capacity to understand, reason, and remember the spatial relations among objects or space. This aspect has been studied by Joakim Vindenes in his Master Thesis[Vindenes2017] and in a following paper[Vindenes et al.2018]. His studies shows a difference of approximately 22% between the groups with the lowest and highest spatial ability. It is therefore really important to normalise the analysis of the studies by considering this factor.

4) Enjoyment, motivation, and compliance: The usage of VR for the MOL demonstrates an important impact on the enjoyment of the participant. For example, [Cho2018] showed, in the analysis of the participant's questionnaire, a difference of compliance in favor of the VR group of about 14%. Yeonhee Cho, in her master thesis[Cho2018], shows an overall increase in the motivation and the enjoyment using HMD instead of Monitors.

These results are strong arguments for the usage of the MOL with VR. As we live in a society that is extremely focused on amusement, having a better enjoyment will increase motivation and compliance which is primordial for some domain. This may also be, one of the arguments that increased the recall performances observed in the previous studies.

5) Applications: The master thesis of Yeonhee Cho presents clearly an interesting application. The learning of the Korean language. Her results validate this concept of VR MOL applied for education. Furthermore, several previous papers took positions for the usage of the VMP.

Fig. 9. Usage of VML for learning Korean vocabulary[Cho2018].

[Hedman and Bäckström2003] were the first to argue in favor of a VMP in the context of philosophy courses through a virtual museum. [Fassbender and Heiden2006] also talked about education through an interesting Cooperative learning virtual environment *VirSchool*.

But the application is not limited to the academy. Elizabeth Losh [Losh2006] reviewed two contemporary projects of the VML for the U.S. military. The first one aimed to lessen Post-Traumatic Stress Disorder among combat veterans, and the second one aimed to learn Arabic vocabulary.

C. Conclusion

1) General overview: Current studies of the VMOL are pretty sparse, but give a reasonable idea of the impact of the different devices(Desktop, CAVE, HMD) on the performance of the MoL. It turns out that usage of virtual MoL seems to allow equivalent or sometimes better memory recall for naive subjects. But

it definitively imply better motivation and compliance. The VEs that include the elements to-be-remembered can be displayed in various ways. The ones that are images or 3D objects seem to be more memorable. About the palace, the usage of a recently learned or a familiar environment doesn't show different performances, which allow a lot of freedom in the elaboration of the palace. But the meaningfulness of the environment seems to be important on the memorization. All these aspects should be analysed more deeply as you can see in Future Directions.

2) Future Directions: A lot of the presented studies are pilots. They assume the fact that the number of subjects is not enough to make meaningfulness conclusions on their results. It would be important to make large scale experiments, but also to consider new information for the evaluation. The most important one would be the spatial reasoning ability as seen in II-B.3. Most of the evaluations are done some minutes/hours after the training/learning phase. To effectively analyse the learning it would be important to also evaluate the long-term memory by doing again these evaluations days/weeks/months after the first one. Which can be complex "Due to difficulties recalling participants back to the lab, the long-term memory test was conducted through an online survey. Half of the participants responded to the survey, rendering the data unusable for the study. "[Cho2018].

A lot of suggestions are given in different papers. Arguing more sophisticated environments, enriched with animations, multimedia or interactive events should be analysed. The visual saliency[2] could be evaluated on the elements to be remembered, the impact of the. As well as comparing elements that are highly personal versus those that could be used by larger groups. The meaningfulness of the Loci should additionally be further analysed between meaningful and meaningless areas. The degree of interaction also lacks experiments and innovative implementations. A more psychological approach would also be interesting, by evaluating how cognitive theories can help to find design principles for highly memorable loci.

III. Pilot Study

In this study, we are focusing on the representation of the ETBRs. The objective here is to compare the efficiency of the MoL in VR with a more or less personal attachment to the represented ETBR. This personal attachment is transcribed by a narrative in the creation of the representation, which is a cube in this study. Our implementation will allow the participants to instantiate one cube per ETBR with two different modes :

- One where the participant will be able to apply one image as a texture on the cube among 10 pre-selected images.
- The other one where the participant can search through a virtual browser an image to apply on the cube.

More details will be given about the implementation and limitation of the pilot study in the development part (IV).

A. Experiment design

This experimentation is divided into different parts to have a better result, with less noise and with some information about the participant to understand some difference between the results. We have 5 steps for this experimentation:

1) We will test the participant to know more about use with spatial test and a pre questionnaire (about 10 min)
2) Then we will explain how to use the application and what is the MoL (about 5 min)
3) The concrete experimentation in the VR world (using the MoL in VR through our application) (about 40 min)
4) A post questionnaire to know the efficiency of this experiment in short term, and an open question to have some information on the app (about 5 min)
5) The last questionnaire, send by mail, three days after the experimentation, it's the most important questionnaire and this questionnaire describes the efficiency of the method. It's only three days after because it's sufficient and because it's hard for us to wait one week. All the tests except the last questionnaire need to be done in 1-hour max.

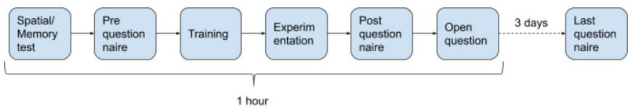

Fig. 10. Representation of the experimentation

In this experimentation, the list of ETBR is a list of ten paradox, with a description. This list has been

[2]Salience (neuroscience) https://en.wikipedia.org/wiki/Salience_(neuroscience)

found in the French Wikipedia[3] and translates for this article. Here is the list used for the experimentation :

1- The paradox of cheese with holes: the more cheese, the more holes; the more holes, the less cheese; so the more cheese, the less cheese.
2- Paradox of the barber: a barber (who is a man) shaves all men and only men who do not shave. Who will shave the barber?
3- Paradox of the lawyer: an apprentice lawyer promises to pay his teacher only after winning his first trial. The professor pursues the apprentice because he has not yet won a lawsuit.
4- Heap paradox: if you remove a single grain of sand from a heap, you still have a heap. By continuing to remove grains, the heap disappears. Does a single grain make a heap disappear?
5- Paradox of friendship: for the average person, most of their friends have more friends than they do.
6- Paradox of the learned monkey: a chimpanzee who types indefinitely and at random on the keyboard of a typewriter will "almost surely" write Hamlet's text.
7- Abilene's paradox: none of the four members of a group wanted to go to Abilene but, for fear of being offended and contradicting each other, they all ended up there!
8- Paradox of tolerance: We should claim, in the name of tolerance, the right not to tolerate the intolerant.
9- Paradox of the egg and the chicken: which appeared first: the egg or the chicken?
10- French paradox: the astonishing contradiction between the richness in fats and French wines of French cuisine, and the relative good public health of the French in terms of cardiovascular disease or cancer.
For the participant who has cubes with an image chosen from ten, the ten images are chosen with an image's search of the french name of the paradox without the word paradox, for example, Paradoxe d'Abilene -> Abilene.

B. Experiment group

The group is composed of 11 persons, 21 to 23 years (mean of 22), and 9 of us are students of Polytech Nantes. We have randomly chosen, for each one, if they will use the searched image's app (cube with an image that is search on the internet) or the ten image's app (a cubes with an image chosen from ten), so 5 of us used the searched image's app and 6 the other one. One of us used the MoL before and the two-third already know the method or a part of the method. And really important, they don't know the ETBR used in the experimentation (or just 1 or 2 ETBR). Both groups used the same map and the same ETBR, only the cube creation method is different. All the participants have the physical condition to used VR and no one was hurt. All the participants were French, that's why the test and questionnaires are in French.

[3]Salience (neuroscience) https://fr.wikipedia.org/wiki/Liste_de_paradoxes)

C. Materials

All this experimentation was done on an Oculus Quest. It is a virtual reality headset created by Oculus VR, a division of Facebook Inc. The device is fully standalone, features two, six degrees of freedom (6DOF) controllers, and runs on a Qualcomm Snapdragon 835 system-on-chip. This headset was launch on May 21, 2019. We register all the experimentation with an integrated functionality of the record. All the application was developed with Unity and for the image, we used the Qwant API. The majority of the experimentation was done in Polytech Nantes, we used some chairs and tables to delimit an area of 2 meters, it's a great place for VR and the participant can move easily in the space.

D. Details

1) Spatial/Memory test: We used a free test to compare our participants. For the spatial aspect we used https://www.123test.com/spatial-reasoning-test/, it's a spacial reasoning test really short because we need a free and short test. It's also a test used to work our spacial memory. 123test is an independent European company, in which the research staff is headed by Edwin van Thiel, PhD in Artificial Intelligence and Psychometrics, who is the co-founder and co-owner of the 123test Company. This spatial test takes 5 minutes. In this test, the participants need to find which cube cannot be made based on the unfolded cube. It's an easy question but it's hard to find the solution for the lasts cube.

2) Pre questionnaire: In this questionnaire, the objective is to have information about the participant and on that mastery of the subject. We ask about the age and the job (and email to send the last questionnaire), that's important to know more about the experiment group. After that, we ask a question about the MoL to know if the participant has already used this technique and if he knows this method, with this information we can compare the result and know our capacity to explain the method. The last part is on VR and on the subject of Paradox. The VR part is to know if the participant

knows how to use VR if he will discover the world and be a bit curious in the early of the experimentation. And the paradox's question it's really important to know if the participant already knows a part of the ETBR of the test. And because with interest, the participant will probably remember the ETBR easily. All of these questions take less than 5 minutes.

3) Training: The training is an important part of the experimentation because we want to have the same bases for all the participant. So we start our speech by explaining to the participant what is the MoL and how to use it. Speech: "MoL is a mnemonic method, practised since Antiquity. The principle is to visualize a place that we know well and to browse it. Then put things in there that we want to remember. Finally, we walk through this place and we review our objects, everything allows us to retain them by going back several times to our palace. Here the palate is already made and is in the headset, you will just add the objects to remember." And after we need to initiate the participant on the VR. So we help us to understand the principle of the guardian on Oculus Quest, it's to help the participant to feel safe. After that the participant opens the application and waits for the start. We explain to the participant the principle of teleportation with the ar to move in the application. After we explain how the menu works, with the list of ETBR on the left hand and the pointer on the right hand. The participant chooses an ETBR (it's a generic ETBR, it's not a paradox) and tries to generate a cube by using the keyboard and the searching area. After that, he can try to manipulate the cube, enlarge and shrink the cube. To finish this training part the participant will use the menu to create a blank map and start the experimentation. All this training takes 10 minutes.

4) Experimentation: The participant is teleported in a new map, it's a medieval map, with a port. He starts on a tower and can back to this tower with the start button on the menu. In this menu, the participant can see the list of ETBR (the list of Paradox for this experimentation). We ask the participant to don't touch the menu but to navigate and explore the map. It's important to know our environment in the MOL and for creating a route. This part takes 5 minutes in general. After that, the participant needs to find the start of his route. We explain the importance to remember the name of the paradox, but also the meaning of the description and the order in the list, that's why we ask to put the paradox in the list's order. After this explication, the participant can start creating the cube and place it. When he has finished placing a cube for all the paradoxes, he can walk one time his route with the list to remember the route and the paradox. When the participant does the next questionnaire, we explore the map to see the cube, the position, the route.

5) Post questionnaire and open question: After the experimentation, we want to know if the participant remembers some information on the paradox. So we start by asking the 10 paradox in orders and with a little description. We also ask which paradox he remember in first and why. After that, we ask to find the description of a paradox in a list of descriptions, to find the order of 4 paradox, and to write the description of the last paradox. We also want to know if the application if good to use, so we ask questions about filing, the efficiency of the keyboard, the movement, the manipulation of cubes. Also about the map and the environment. We ask some questions about VR, to know if they like this type of headset and if they were sick. We finish with questions on MOL, if they like the method and if it's a good method for us and just an open question about the experimentation and the application.

6) Last questionnaire: After 3 days we send an email with a form on the paradox. This questionnaire is mostly the same as the paradox part of the post questionnaire. With the question about the 10 paradox in order with description, the question about description, about order and others think like that. And just a last question about the MOL, if they remember the method, and we finish with an open question like the previous questionnaire.

IV. Development

In this section, we will go through the requirements and purpose of the different features of the application used in this experimentation.

A. System and software requirements

As described in the scientific state of the art, different versions of the Virtual MoL has been developed. Often, these software were minimalistic by their functions, design and implementation. The following sections will explain each feature and its importance.

1) Egocentric view and displacement: An egocentric view is essential in this context to use the advantages of the VR. The user is able to see the world and move around using Oculus' controllers. To avoid motion sickness, the displacement is done through a teleportation system activable with the index trigger and visualized with a laser. Rotation of the view is

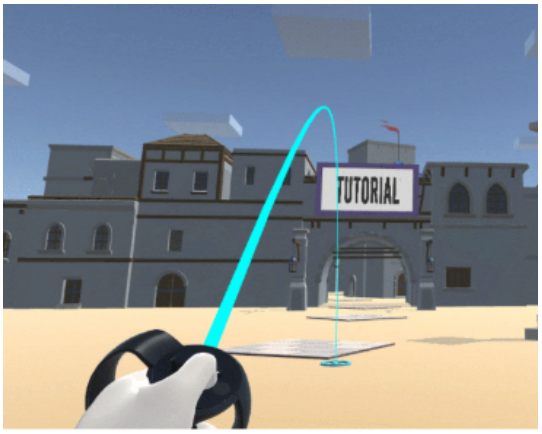

Fig. 11. Virtual representation of the Oculus' controller with the curved teleport laser activated.

available using the thumbsticks. To help the user to understand it's controller, a virtual version of them was visible in place of the real ones. Collision with the map where activated, avoiding incoherent movement. However, the user's avatar (virtual representation of the user) wasn't subject to gravity, to avoid falling off the map or glitches.

2) ETBR's Menu: Through an activable menu display on the left hand, the user is able to see the list of the ETBR allowing a simple overview and several features. In this menu, the user can interact with a laser pointer tracked on the other hand. Once an ETBR selected the right part of the menu is adapted to display its description, the number of cubes related to it, allow to remove these cubes and allow to create a new cube. The ETBRs that has at least one cube are represented in green to improve the visibility of the remaining ones.

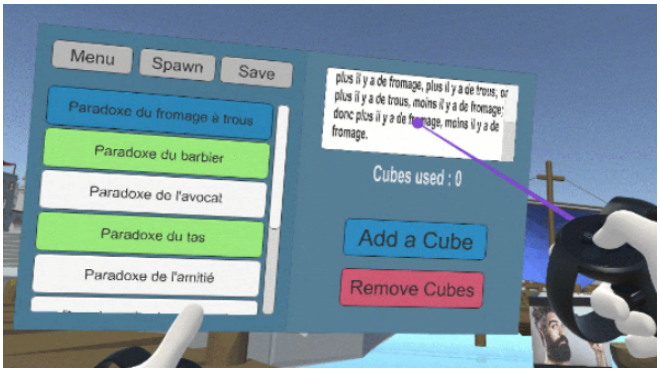

Fig. 12. The ETBR's menu with the list of paradox used in the experiment.

Furthermore, this menu allows the user to go back to the "Home Menu", save the palace at its current state and being teleported at the palace's spawn (the place where the user starts its journey in the palace).

3) Cube creation: Once the "Add a Cube" button clicked inside the ETBR's Menu, the cube creator is displayed and the current map is visually removed. In this creator, the user can use the teleporter laser. On the right the name and description of the ETBR is displayed, on the left the cube, a quick reminder of the task (containing "Search and select the image that will be applied on your cube to be able to use it"). In front of him, there is a browser where he can search for images with a virtual keyboard. These images are retrieved through the Qwant image API. With a laser in its right hand, the user can select one of the images, which will directly change the texture of the cube. Once the user is satisfied, he can use the laser to confirm the cube creation and will come back in the palace.

Fig. 13. The cube creator with the query "cheese" used and the first sprite applied on the cube.

4) Interaction with the cubes: The user can move and rotate the cube by grabbing it with the hand triggers (see Annex). He can change its size as well by moving forward or backwards the thumbstick of the controller that is holding the cube.

5) Home Menu and Tutorial: Once the user is in the game, he starts in the "Home menu". A map where he can learn more about the MoL and how the application works through a quick tutorial which consists of several consecutive signs.

6) Saving and loading: Inside the "Menu Temple" a UI allow seeing the different saved Palaces, it is possible to load or delete these palaces. To save a palace the user can simply click on the save button inside the ETBR's Menu while he is in the palace. The application makes also an auto-save when the user creates a new cube or removes one.

7) Palace creation: In the limit of this study, only one map and one list of ETBR was used. But we propose a wider usage by allowing in this application the "creation" of several palaces. We consider that a palace is a list of ETBR associated with a map. One map can be associated with several lists but not the contrary. So, in the temple the user can create a new

palace by selecting one list of ETBR, then one map to be able to go to the palace. The different maps are directly stored in the executable but the lists are hosted in a distant website. Which allow to update the number of list of ETBR without the need to update the application.

8) Maps: The application contains four different maps used as "Palace". An adaptation of the city of a Unity asset "Polylised - Medieval Desert City" has been adapted to have a condensed, memorable and easy-to-navigate map. This map is the "Medival Port" and is the only map used in the experiment. The three other ones are available on the application and are built using Google Poly Models or Unity Assets.

B. Coding

This application has been made with unity. A lot of functions are needed to use the VR hardware and common features. We used the Oculus VR SDK to be able to implement the different features. This SDK contains a bunch of scripts, models, prefabs, scenes useful to understand and develop on Oculus. Most of the features have been developed with C scripts and the unity native functions. To keep track of evolution and to have backup a simple GitHub repository has been used.

C. Testing

This application has been developed in continuous development in a time-laps extremely constrained. A list of bugs has been defined and progressively solved until a usable version of the application has been made for the experimentation.

V. Result

A. All participant

1) Participant profile: Like we explain in the previous part, the 11 participants are in majority student of Polytech and have 22 years. This two graphics explain the distribution of participant :

The participant responded to a spatial test: https://www.123test.com/spatial-reasoning-test/ and have a grade. We will try to compare this grade with different results, but first, let's see the repartition of results :

Like we can see, nobody have less than a grade of 5 and the majority of the participant have more than 8. One of the problems of our experimentation is the resemblance of the participant That's probably the reason for the grades and the high score.

We have also asked the participant if they have some disease that can be important to note for a VR experimentation.

We can see one colour blind and a majority of nearsighted. A good point with the Oculus Quest is the possibility to use it with glasses, that's why we don't have a real problem with nearsighted, they just use the glasses. One of use tries to use the headset without glasses because he thinks the screen is in front of his eyes. But without glasses, he saw a blur and he finally uses the glasses for the experimentation.

2) Knowledge about MOL before experimentation: We ask some question about the MoL, to know if they already use the MoL and if they know this method. 3 of us know the method of the array, and only 3 participants of the 11 don't know the MOL. For the participant who already knows the MoL, only one of us uses the method before.

3) Opinion of VR: We also ask a question about VR. Because if they already use VR, they probably know some basics and they have some reflex. 2 of the participant never use VR because they don't have the opportunity. And the 9 others use the VR in a different way :

We are in an engineering school in computer science, so some of our participants have already used the VR for development of for visualisation. It's really interesting because the person who develop know the different type of convention, for example, the type of movement in VR. And for the person who plays, they generally play Beat Saber and they have some habits for menu and we see this in the facility to use our menu.

In this 9 participant, only 3 already use a fully standalone headset. The 6 others use a classic headset, and they can compare the difference with Oculus Quest after the experimentation.

After the experimentation, they all say they like VR and 10 of us say the fully standalone headset is good. And one says he didn't see any difference with the classic headset. But in general, they say it's really interesting to don't depend on other object and to be free to use it where we want, for mini-game for example. Only one says the experimentation was too long.

4) Knowledge about paradox: We need to know the knowledge of the participant in term of paradox because the list of ETBR for experimentation is a list of paradox and if they already know our list they will probably remember easily. And if they like the paradox they will probably be more motivated and have a better memorisation. All the participant know the principle of

the paradox, but they aren't equal in knowledge level :

For the list of ETBR we have, a part of the paradox is "level 1" but some ETBR are really specific and when we talk with the participant, they don't know more than 2 or 3 elements. For this 2 or 3 elements generally, the participant remembers easily the description of the ETBR.

We ask if they are interested in the paradox :

In general, they are interested in the subject. We can imagine this result will impact the memorisation. Only 3 participants consider their interest to be less than 3 of 5.

5) The opinion of the VR after the experimentation: We have asked 4 questions about our VR application to know more about the interaction.

Let see the repartition of the response :

We have the same results for the keyboard and the search engine. With a mean of 3, we can interpret the keyboard and search engine is good but need to be upgraded. This two elements can possibly influence the experimentation and can possibly influence the memorisation. For the cube's manipulation, the majority of the people like the application, but one person ask for a little gravity to be more real. And we finish with the movement technique, the technique is effective, only one participant doesn't like the movement technique and we can imagine it's because of the little bug of collision when we walk close to the wall.

For the environment, some participant wants some life, like PNJ or animals. The only point really important for interaction is to modify our application to allow the users to swap of hand to type on the keyboard.

B. The group with searched image's app (SIA)

1) The memorisation of paradox after the experimentation: In the test after the experimentation, for the group SIA, we have really good results. Two participants have reversed two paradox for the order but for the rest, they have found all the paradox in the good order. For some paradox, they don't find the exact name, in total they fail 14 times. Especially for the paradox with a name, like the Abilene's paradox.

2) The memorisation of paradox after three days: For the questionnaire after three days, we have done the same type of questions as the previous questionnaire but this time we have also noticed the description of all the paradox. The participant have a good result, they have the same mistake for the order as the previous questionnaire. They fail for the exact name only 3 times, probably because they were more concentrated. One of us don't remember any description and for the 4 others, they do 5 fail in the description. We also ask which paradox come back in first when they try to remember the ways. And only one of us has changed this paradox between the post questionnaire and the last one.

3) Some other questions: In the other questions of the test pre experimentation, they all find the good description and the good order. 2 of the 5 find in first the egg and the chicken because it's the most popular paradox, 1 the tolerance paradox because he says it's the most "funny", 1 the cheese because it's the first one, and the last 1 the learned monkey paradox because the image in the cube is prominent. In this group, we also have the only person who doesn't remember the description of the french paradox (it's the last question).

C. The group with ten image's app (TIA)

1) The memorisation of paradox after the experimentation: In the test after the experimentation in the group TIA, one participant has reversed three paradox, and one of us has failed all the order. We tell him to put the cube in the order of the list but he didn't put it in the same order. That's why when he tries to remember he can't find the order of the paradox. This time in the group they don't find the exact name 24 times. And especially for the paradox with a name, like the Abilene's paradox.

2) The memorisation of paradox after three days: For the questionnaire after three days in the group TIA, we have also noticed the description of all the paradox. The participant has a good result, they have found the good order, except for the participant who didn't put the paradox in the order of the list. They fail for the exact name only 9 times, it's better than the post questionnaire, it's probably because they were more concentrated. One of us doesn't remember any description and another one fail 6 descriptions of 10. The others don't do any fail.

3) Some other questions: In this group only the participant who didn't put the paradox in the good order didn't find the response for question of order. But they all remember the description and this time 3 of the 6 remember the cheese in first because it's the first one, 2 the french, and one says it's because he is french, and the last 1 the egg and the chicken because he is famous and it's one of the last.

D. Comparison

When we compare the results of the two groups, we see a difference in the accuracy of the name :

As we can see, they are all more efficient to remember the exact name after three days. It's probably because they are more focus. Or it's because the method works well after some days. We also see the difference in the group. The group SIA have better result for the accuracy of the name probably because they choose the better image to remember the name. We can imagine that for the complex name of paradox. For the Abilene's paradox, for example, it's possibly more easy to remember a name like Abilene when you choose your image.

For accuracy of the description the difference is insignificant :

We think the list of paradox was too short and too easy to remember. That's probably why the result aren't so different. It's also possible to have a difference because of the profile of our participant. We have a problem of planning, but it will be better to ask the last questionnaire more than one week after the experimentation.

E. Some other commentary

We have done a map of all the routes (without the participant 11, we don't have the route) :

All the routes are really different, some participants have put the cube near to an object who has a relation. Like the barber's cube near to the little shop.

One of the participants have a done the same mistake in the order in the two questionnaires, and when we see the map (P4) we see a route with a lot of crossing, that's a possible reason of the mistake.

In general, they all have re-travel their route to remember the paradox and the order, with only 10 paradox the MOL in VR is really efficient and expect the participant who doesn't put the cube in the order and 2 others who swap 2 paradox in the orders, they have a really good results for remembering the orders and the name/exact name.

VI. Conclusion

A. The MOL in VR in general

The MOL is a powerful method and as several articles demonstrated, it can be perfectly adapted in VR. In the state of the art section, an overview of the objectives of the previous articles has been done. Among these objectives, comparisons between hardware, participant abilities and software design have been done. This article brought out some way to upgrade the MOL in VR. Like a sophisticated environment, with animation or interactive events.

B. Our experimentation

We decided to explore in detail the process of representation of ETBR. The different constraints of our project forced us to evaluate the SIA and the TIA. In fact, our first idea was to compare the efficiency between memorizing abstract elements with 3 cubes or with one cube. But the time to create a cube was too long to apply the comparison for an interesting amount of ETBR. That's why it has been decided to compare a person who searches the images against a person who has the choice between ten images for ten ETBRs (leading to experimentations of one hour per participant). Which allowed a simple and doable way to compare a more or less investment of the participant in the process of creation of ETBR's representation.

C. The results

We saw some interesting result, like differents way to explore the map and different images chosen by the participant. Participants took initiatives and appropriated the MoL, each of them had a personal strategy in navigating in the map, placing the cubes and interacting with them.

More interestingly, we saw an important difference between the group that has been more invested in the process of cube's creation(which are the representation of the ETBR).

The satisfaction and motivation of the participant were extremely high for this experimentation. A lot of interesting feedbacks have been given and some of them reported new interest in the method of loci afterwards.

D. Limitation

However, these results can't be really considered as the number of participants was to low and several different biases could explain or affect the results. Despite several concession in term of experimentation, the number of participants was too low and time-consuming to have statistically significant data. The list of ETBR was a bit too easy, to have a real result we probably need to remake this experimentation with more participant, more ETBR and to see the memorisation after at least one week.

E. Future directions

Further experimentations should be done with a larger number of users, longer duration of the experiment, and increased complexity in terms of elements to remember.

In our study we let the user define by himself the path to follow, which led to a lot of different approaches in the navigation by the users. The importance of the path could be evaluated. New ways to represent complex ETBRs could be imagined, developed and compared to improve the efficiency of the method. The conception of the palace could also be a really interesting thing to analyse. Procedurally generated palaces with more or less complexity could be tested in another experiment.

VII. Acronyms

- VR : Virtual Reality
- VE : Virtual Environment
- MOL : Method Of Loci
- ETBR : Element To Be Remember
- SIA : Search image's application
- TIA : Ten image's application

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APPENDIX

The instructions to use the MOL (Legge et al. 2012)

The Method of Loci has been proven to significantly increase the effectiveness of memory. Below is a description of the Method of Loci, paraphrased from The Art of Memory by Yates, the established historical text on the Method of Loci. 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.

Oculus controller

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Comparison between the implementations

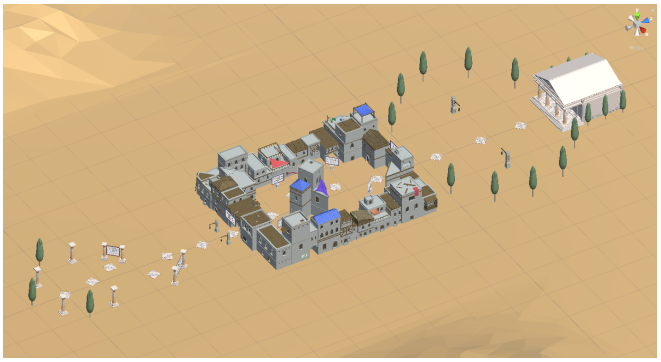

Fig. 14. A isometric overview of the home's map. The user starts in the bottom-left corner and can see the signs of the tutorial through the little city. He can then go to the "Menu Temple" to create or load a palace.

Fig. 15. Interior of the "Menu Temple". On the left the UI used for creating a new palace. On the right, the saved palaces manager.

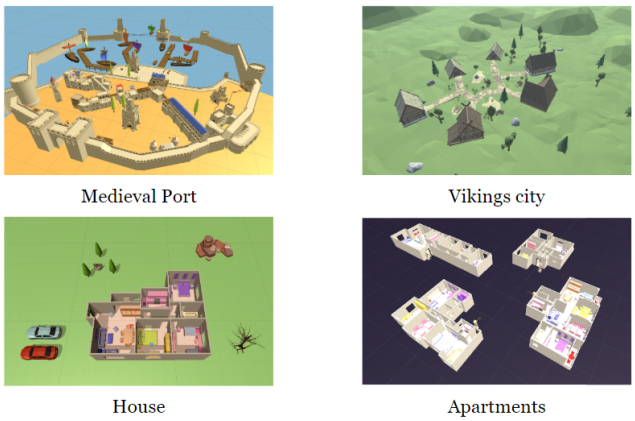

Fig. 16. Overview of the four available maps.

Articles	Environment	Indication on the path	External MOL	Free Movement	Placement of the ETBR	3D	Text	Image	Animation
Reggente et al. 2019	Ruins, Lagoon and Apartment	x (tokens)		x	Arbitrary or By the user	x			
Vindenes et al. 2018	Apartment			x	By the user	x (Memory Cube)		x	
Huttner and Robra-Bissantz 2017	Apartment		x	x	None	-	-	-	-
Krokos et al. 2018	Ornate palace and medieval town			Rotation Only	Arbitrary			x	
Vindenes et al. 2017	Apartment			x	By the user	x (Memory Cube)		x	
Hedman and Backstrom 2000	Museum			x	Arbitrary	x	x		
Taavi Kivisik 2016	4 locations with more or less Meaningfulness and Segregation		x	x	None (but specific loci where hilighted for the external MOL)	-	-	-	-
Huttner et al. 2018	Apartment	x		x	Arbitrary		x	x	
Mann et al. 2017	Virginia Tech's University	x		x	Arbitrary	x	x		
Yeonhee Cho 2018	Classroom	x		x	Arbitrary	x	x		x
Legge et al. 2012	House, school, warehouse		x	x	None	-	-	-	-
Fassbender and Heiden 2006	Castle			x	Arbitrary	x		x	x
Jund et al. 2016	Apartment	x		Only go forward on a precomputed path	Arbitrary			x	x

TABLE II

ENVIRONMENTS, FORM OF THE ETBR(ELEMENTS TO-BE-REMEMBERED) AND INTERACTIONS IN THE EXPERIMENTS

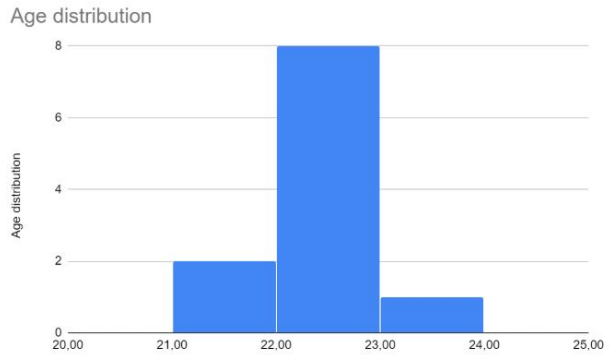

Fig. 17. Distribution of ages

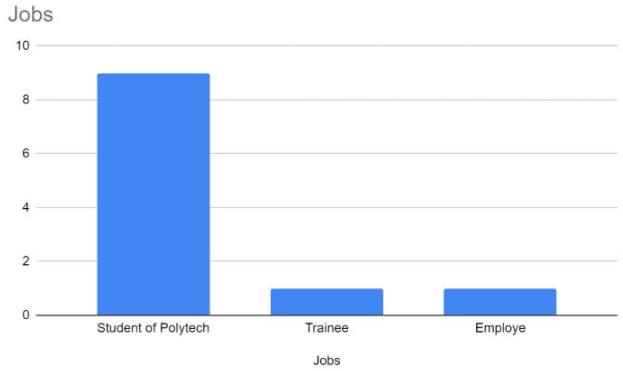

Fig. 18. Distribution of jobs

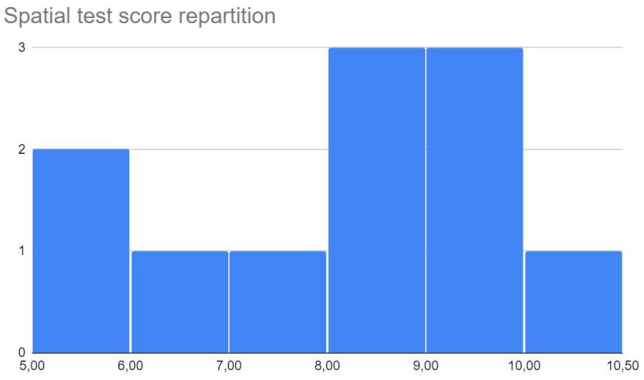

Fig. 19. Distribution of spatial test's results

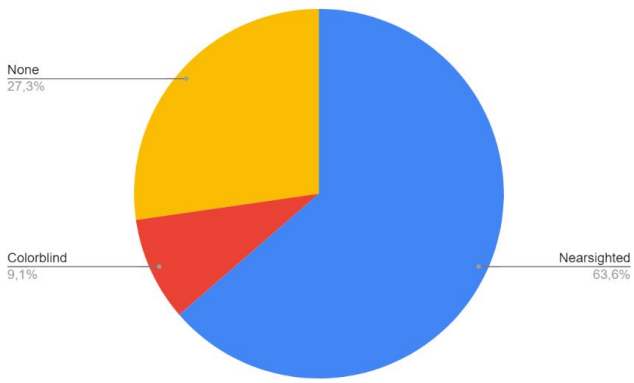

Fig. 20. Differents desease

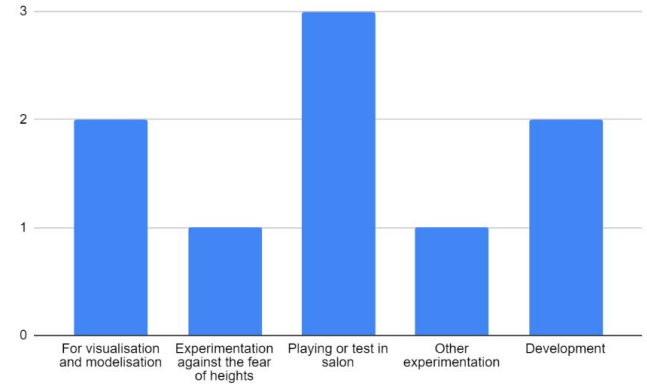

Fig. 21. Type of uses

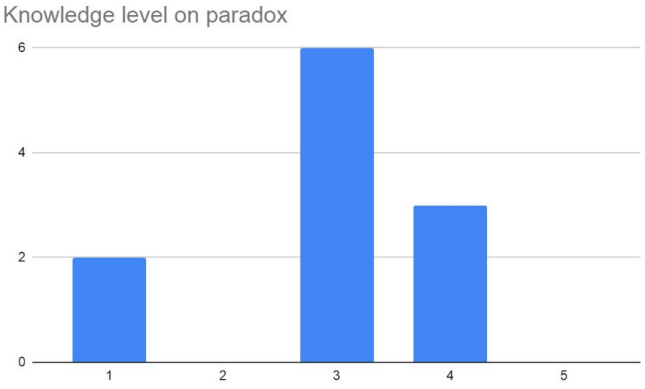

Fig. 22. Knowledge level on paradox

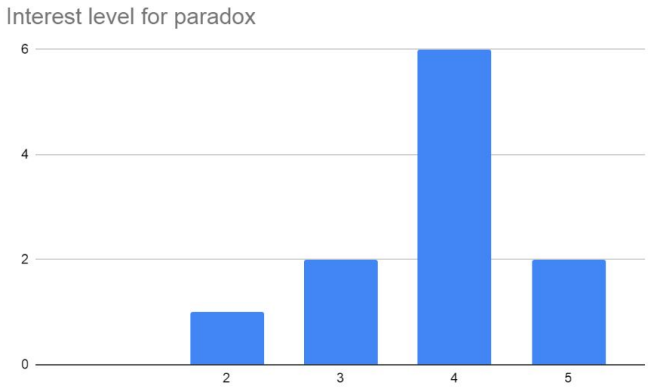

Fig. 23. Interest level for paradox

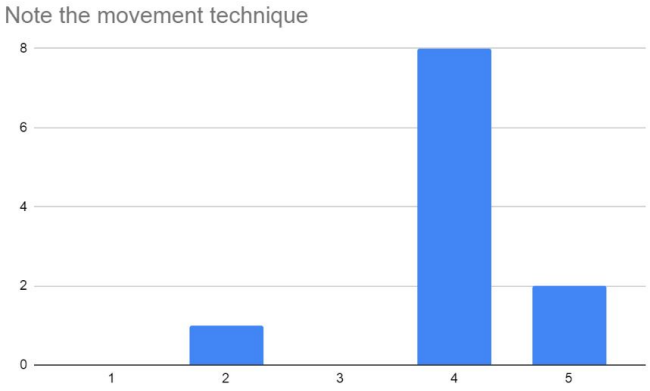

Fig. 24. Note for movement technique

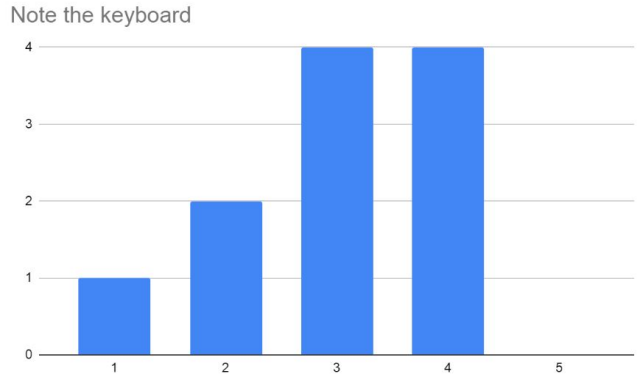

Fig. 25. Note for keyboard

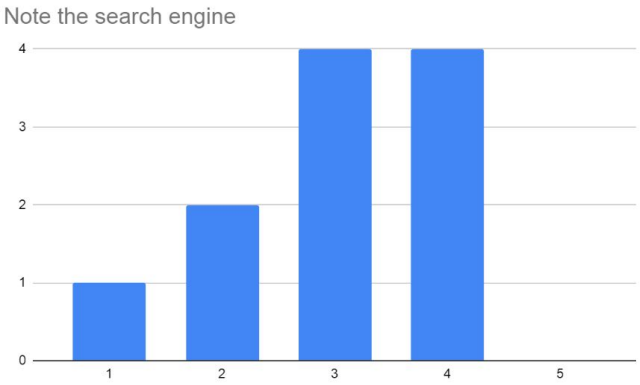

Fig. 26. Note for the search engine

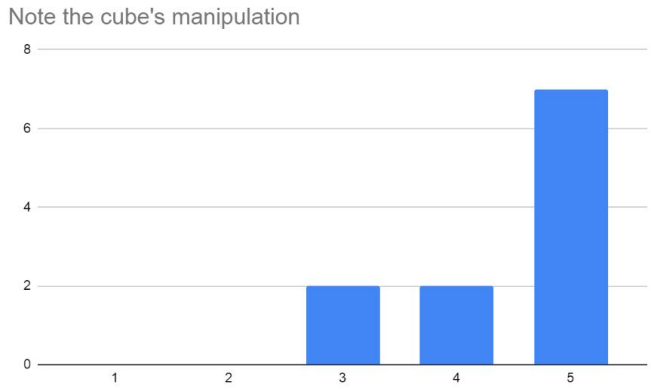

Fig. 27. Note for cube's manipulation

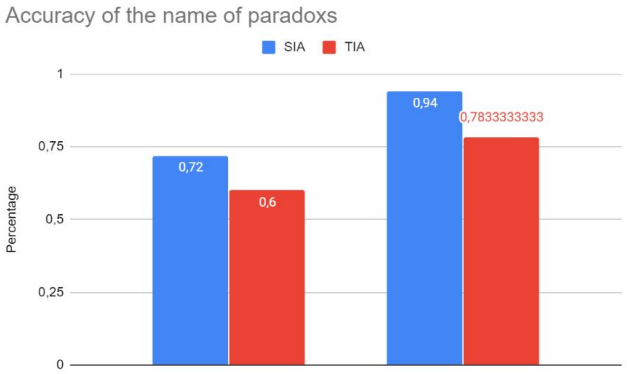

Fig. 28. Accuracy of the name of paradoxs

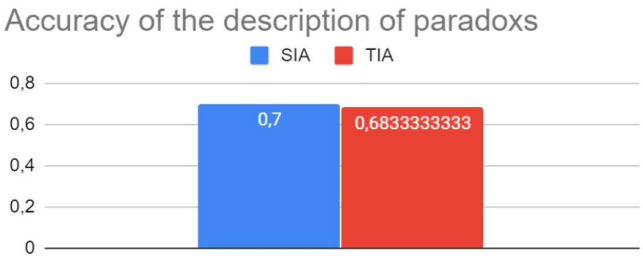

Fig. 29. Accuracy of the description of paradoxs

Fig. 30. The map of the routes

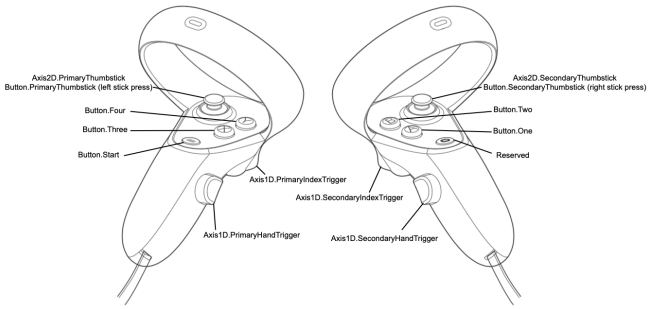

Fig. 31. Oculus controller triggers names.