Impact of frame of reference on memorization in virtual environments

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***Abstract*—In this paper, we investigate the effectiveness of using virtual environments for memorization tasks in the context of learning activities. Our approach relies on the Method of Loci. To that purpose, we conducted an experiment comparing egocentric and allocentric representations and incorporating a navigation task. Our results show that an egocentric frame of reference offers the best spatial cues to help memorizing lists of items.**

I. Introduction

Virtual Reality (VR) has long suffered of three main drawbacks to fully integrate educational settings: cost, usability and fear of the technology [1]. However, with the development of the last generation of VR technology and the democratization of head mounted displays, VR might be on the verge of becoming a powerful tool for the future of education. VR-based applications for learning are spreading as they offer the possibility to improve engagement and help to develop sophisticated problem-finding skills [2].

Some of these applications try to improve the memorization task or propose captivating scenes to motivate a learning process [3], [4]. Indeed, VR ensures increased feeling of presence and higher immersion. However, it is still not fully known how VR might be exploited in learning activities. If presence has been shown to be positively correlated to flow [5], confirming its potential benefits for educational purposes, other results suggest that presence might not positively influence behaviors in VR but rather induce harmful effects [6]. As for immersion, it seems to be of advantage only when the content to be learned is complex, 3D and dynamic [7].

Considering learning processes, Method of Loci (MOL) has long been considered as a suitable mnemonic device for VR environments. This ancient memorization technique has been used since antiquity, initially by rhetoricians, in order to accurately deliver long speeches [8]. It relies on using known places (real or imaginary, most commonly architectural places) and to associate specific items to each place. Recollecting an ordered list of items (being concepts, objects, procedures and so on) is then achieved by mentally traveling a predefined path in the memorized places.

Given its intrinsic spatial nature, VR seems to offer the perfect technology devices to implement MOL. Not only it allows to offer immersive exploration of any given architectural environment, but it also provides rich sensory cues (spatial contiguity, optic flow, self-directed navigation). It is not clear, however, which kind of spatial cues are best suited for such VR applications. Further research is needed to understand what design features most contribute to memorization, especially if VR is to be used in learning activities.

In the present paper, we want to analyse the effect of egocentric and allocentric spatialization on memorization performance within an immersive scene. We studied the impact of three main factors on recall performance: frame of reference, knowledge of the architectural environment and navigation.

This paper is organized as follow: the next section presents related work and discusses their contributions to our study. Section III describes our experimental study to investigate the impact of spatialization and navigation on memorization. Section IV and V provides the obtained results and their analysis. Finally, section VI concludes this work.

II. Related Work

It is now accepted that VR can efficiently be used for learning sophisticated cognitive skills, in particular through the use of situated learning [2]. Another approach is also to use Immersive Virtual Environments (IVEs) to improve memorization performance, especially through MOL. Legge et al. [9] conducted a study to know if virtual architectural scenes could be used as a basis for using MOL. In their experiment, participants, who were beforehand introduced to MOL, were asked to use the technique either with a mental representation of their house or a mental representation of a virtual environment they visited during 5 minutes. The accuracy of the recall phase was equivalent when using a virtual environment and a conventional one. Unfortunately, this study does not show that VR can be used as a memorization device, since the memorization is performed afterwards, outside the virtual environment, using conventional MOL. The method itself is not implemented within the environment.

Ragan et al. [10] showed that the use of egocentric spatial information in an IVE significantly increases recollection when the memorization of a sequence of items is involved. However, their experiment did not explore the impact of an allocentric frame of reference, as it is used in MOL.

Bowman et al. [11] and Ragan et al. [12] showed that IVE can successfully be used for procedure memorization. They also studied the influence of the degree of immersion on recollection performance. By modifying the size of the used screens or the field of view during their experiment, they revealed that a higher degree of immersion leads to better memorization. However, they were not interested in the influence of the frame of reference used to enhance memorization procedures.

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Other VR-related cues may influence learning processes: control, decision making, sensory cues, etc. Bowman et al. [11] showed that higher levels of visual fidelity support better performance for procedure memorization. This suggests that environment characteristics have a significant impact on memorization performance. Bakdash et al. [13] studied the effect of decision making and control for learning spatial information in a virtual environment. It showed that decision making, more than interaction, was important for this learning task.

Suma et al. [14] performed a study of cognitive effects of travel technique. Their experiment showed no influence of the corporal implication on the task of memorization, suggesting that virtual travel is as efficient as real walking for exploiting spatial layouts for learning activities.

Our prior objective is to know whether IVEs are suitable for using MOL in order to support learning tasks, and which spatial characteristics are better for this purpose. Few studies were already interested in this approach, however none, as we know of, focused on the influence of egocentric *vs.* allocentric frame of reference on memorization. Since other environmental characteristics, such as interaction, may also have a significant influence, we also studied the impact of the navigation technique on the performance in the allocentric condition.

III. Experimental framework

In this section, we present our experimental framework.

A. Experimental environments

Our experiment is performed in a semi-immersive environment providing stereoscopic display. The screen is 3m wide and 2.25m high. It has a resolution of 1400×1050 pixels and a refresh rate of 2×60 Hz. We used CristalEyes CE-2 glasses, synchronized with the screen, to ensure stereoscopy. The interaction device was a Nintendo Wiimote. Both the head and the Nintendo Wiimote are tracked using a Vicon tracking system, with 6 Bonitas cameras and optical trackers.

We set up two egocentric environments (figure 1). The first one was designed to present series of images to the participants with no spatial information. The items appear successively in front of the user. The second uses an egocentric frame of reference. All items appear one after the other following a circular shape around the user. This circular shape is shown to the user with 10 circular poles during the complete duration of the memorization task. This scene matches the previous experiment performed in [10]. In both environments, each item is presented to the participant for a duration of 4 seconds. Between two successive images, there is a pause of 10 seconds during which no information is given to the participant.

The last environment was designed to rely on an allocentric frame of reference. To allow an easier implementation of MOL, we chose to use a place that we thought would be suitable for the task: a virtual apartment. We assumed that each location could then be identified through its use in everyday life. The apartment is composed of nine different locations: entrance, main bedroom, children bedroom, office, kitchen, bathroom, reading room, patio and balcony. Rooms are connected through a corridor (figure 2).

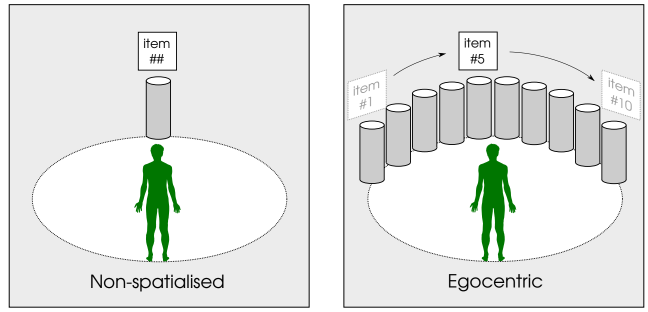

Fig. 1: The two egocentric environments. Left: with no spatialization. Right: with an egocentric spatialization.

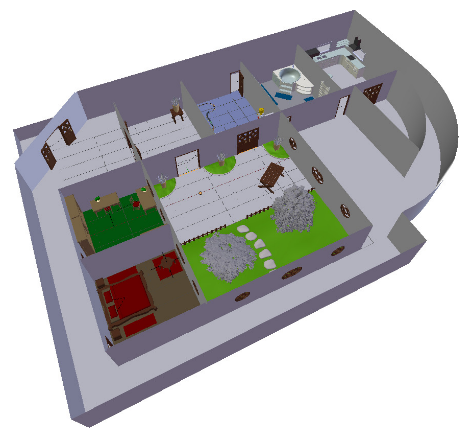

Fig. 2: Global view of the allocentric environment.

In this experiment, we wanted navigation (which can have an important cognitive cost in VR) to interfere as little as possible with the memorization task. We chose then to implement a passive navigation technique. The technique uses a precomputed path and the user only controls its displacements by pressing a button on the interaction device when he wants to move forward. When the participants arrives at a new display point, the item is displayed for a duration of 4 seconds. Trajectories between items and velocity were chosen in order to respect a delay of approximately 10 seconds between each item, to replicate the conditions of the two egocentric environments. However, given the necessity of letting the user have a minimum of control on the environment, this delay might slightly vary between users and experimental sessions.

B. Participants

22 voluntary subjects (students and people working at the university) took part in this study. They have various levels of experience in VR (ranging from subjects that discovered the environment during the experiment to subjects that occasionally used the environment). They were 20 male and 2 female participants, aging from 23 to 35 years.

Fig. 3: A few images taken from the set of stimuli.

C. *Questionnaires and stimuli*

During the experimental session, the participant is first asked to answer a sociological questionnaire. This questionnaire is used to assess the participants age, education level, 3D gaming profile, and familiarity with 3D environments.

Simulator sickness was measured using the Kennedy-Lane Simulator Sickness Questionnaire (SSQ) [15]. The questionnaire was administered before and after the VR sessions.

For this experiment, we did not want to use visual stimuli that offer semantic cues, to avoid the use of non-spatial memory strategies such as repetition. So, to force the user to use other memorization strategies that could better benefit from spatial information, we chose to use non semantic images. Consequently, we used abstract colorful stimuli, taken from a dataset of images used in several experimental studies on visual memory [16]. We randomly chose 30 images from the initial set of 200 stimuli of the database (figure 3). For each test, 10 items are randomly chosen in this set.

D. *Experimental procedure*

The experimental session begins with an oral presentation of the experimental procedure. A printed copy of the instructions, with added images, are given to the participants. They could ask questions at any moment during this process. In particular, we insist on the fact that the participant will have to recall the list of items in the order they were presented to him. During this briefing, the participants are briefly introduced with MOL to help them to capitalize on the virtual environment, and also to narrow the possible cognitive strategies that might be used by each participant during the experiment.

The participants are then provided with a training session. This session allows the subject to familiarize with the navigation technique, so that interacting does not interfere with the memorization task. The training session is stopped when the user is confident about his use of the technique.

Before the protocol begins, we ask the user to fill the first SSQ questionnaire. The participant is then equipped with the CristalEyes glasses, and positioned in front of the environment at a predefined position. The memorization tasks then start. Each subject has 6 different lists to memorize, 2 for each condition. To avoid any ordering effect, we used a Latin square distribution of the order of presentation of the environment.

After each list, the system is paused. The participant is asked to rest for a few minutes. This phase has the purpose of distracting the participant, in order to avoid him from using a repetition memorization procedure. During this phase, he is asked to perform a set of 11 simple mental calculations. Overall, this interfering phase lasts for 5 to 6 minutes.

Once it is completed, the recall procedure begins: the participant is presented with the list of 10 items used during the session, and is asked to order them accordingly. To calculate a recall performance, we computed a distance between the given answers and the correct ordered list. At each item, we associate a recall score equal to the distance between the recall position and its real position. The restitution score is the sum of these values. Afterwards, we resume the memorization tasks.

When all the memorization tasks are completed, the participant is asked to fill a second SSQ questionnaire.

E. *Hypotheses*

Our working hypotheses are the following:

- an egocentric frame of reference improves memorization accuracy. Following the results of [10], we expect the participants to obtain higher recall scores when using an egocentric frame of reference *vs.* no spatial information. We expect that egocentric spatial information will help the participant to embed the information in the environment, and better recall the series of items.
- an allocentric frame of reference improves memorization accuracy, when compared to no spatial information. Following [11], we believe that using high quality IVEs and active navigation can give supplemental spatial information to the participants and help them during recollection. We think that any possible increase in the cognitive load induced by the navigation technique can be compensated by the enriched kinesthetic cues in this situation (head rotations, navigation). In consequence, we expect participants to obtain equal scores in the egocentric and allocentric conditions.

IV. Experimental results

Previous results showed the influence of gender on spatial reasoning [17] and memory performances [18]. Moreover, there are also sex differences in landmark utilization that can have an impact on navigation and memorization strategies in virtual environments [19]. Given those results, we are aware that having an even distribution between male and female participants would have been more appropriate for this study. As explained in the previous section, we had 20 male and 2 female participants. To avoid this uneven distribution from influencing our results, we chose to remove the data of the female participants from the study.

For the statistical analysis, we first performed the Shapiro-Wilk and Bartlett tests to verify if our data fulfilled the conditions of normality and homogeneity. When these conditions are respected, we realized a multi-factorial ANOVA at a 5% significance level. Otherwise, we performed a non-parametric Friedman rank sum test, and pairwise comparisons using the Nemeneyi post-hoc test.

TABLE I: Recall performance for the 3 conditions N-S, ALLO, EGO.

Condition		
N-S	ALLO	EGO
8.35	9.35	3.21

For this experiment, we had 3 memorization conditions: No-Spatial cues (N-S), Egocentric frame of reference (EGO), Allocentric frame of reference (ALLO). Our dependent variable was the memorization performance at the recall test.

We used SSQ results to verify that the experimental conditions did not lead to an increased level of sickness, that could influence memorization performance. A Spearman correlation value was computed. There was no correlation between these two variables (Spearman rho = 0.07, p = 0.669). While the overall simulator sickness level was relatively high (mean = 27.25, sd = 15.43), it seems that recall performance was not related to simulator sickness during the experiment.

The statistical analysis reports a significant influence of the frame of reference on the recall performance (F(2,18) = 10.05, p = 0.0006; see table I). Participants perform significantly better when the stimuli are presented in the EGO condition than in the N-S (p = 0.01) and in the ALLO (p = 0.017) conditions. Pairwise comparison showed no significant difference between N-S and ALLO (p = 1).

Those results confirm our first hypothesis, stating that the use of an egocentric frame of reference in memorization tasks in an IVE increases memory recall accuracy. As such, they are consistent with previous results [10]. However, we were surprised to note that the use of an allocentric frame of reference not only led to lower recall scores than the use of an egocentric frame of reference, but showed no improvement when compared to the reference situation, were no spatialization was present. This suggests that the participants were not able to exploit spatial information in this condition. This contradicts a previous study where the use of a VR environment in a memorization task showed that such an environment could be used with the same level of performance as a known real environment to use as a memorization device with MOL [9].

From this first experiment, we cannot conclude that VR allocentric spatial information can be efficiently used to improve memorization. However, since the participants were able to benefit from spatial cues in the egocentric condition, this could be the consequence of some experimental drawbacks. One hypothesis is that the lack of knowledge of the environment, despite the choice of using a standard environment such as an apartment, was detrimental to the recall performance. Improving the knowledge of VR environment might help to obtain better scores, as suggested by [9]. Another possible factor is the cognitive load associated with the navigation task. It is possible that, despite our efforts to limit its impact, the navigation task has interfered with the memorization task. Thus, we chose to conduct a follow-up study to assess wether these two hypotheses could explain these disappointing results.

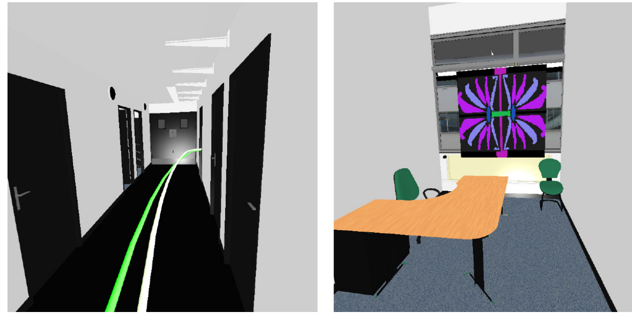

Fig. 4: Two images of the allocentric condition.

TABLE II: Recall performance for the knowledge and navigation conditions.

Knowledge condition		Navigation condition	
UE	KE	CN	FN
9.37	5.90	7.30	8.05

To that purpose, we created a new VR environment where we chose to model the actual hallways and offices of our laboratory (figure 4). Given the fact that participants were undergraduate students, PhDs and assistant professors working in the same building, it was a way to make sure that they would share equal knowledge of the environment. We also added a condition were the participants could freely navigate in the environment, in order to variate the cognitive impact of the navigation technique. We expect that free navigation will end-up with an increased cognitive cost that will impact the recall performance. This could allow us to validate that the cognitive impact of secondary tasks such as application control or navigation have a negative influence on memorization.

Our independent variables are knowledge of the environment (Unknown Environment (UE), Known Environment (KE)) and navigation condition (Constrained Navigation (CN), Free Navigation (FN)). Again, our dependent variable was the memorization performance at the recall test. We had the same subjects participating in this second experiment than in the first one.

The statistical analysis reports a significant influence of the level of knowledge on the recall performance (F(1,18) = 6.658, p = 0.013). Participants perform significantly better when they have previous knowledge of the environment (table II). The navigation condition does not have a significant influence on the results (F(1,18) = 0.177, p = 0.676). There was no significant interaction between the level of knowledge and navigation condition (F(1,18) = 0.918, p = 0.342). Again, there was no correlation between recall performance and simulator sickness (Spearman rho = 0.083 p = 0.539). While the overall simulator sickness results were relatively high (mean = 23.71, sd = 17.16), it seems that recall performance was not related to simulator sickness during the experiment.

V. Discussion

Our first study results were surprising to us. The use of an egocentric frame of reference showed a positive influence on the recall performance, which is consistent with the findings of [10], [12]. However, while we expected the allocentric condition to help the participants to better memorize lists of items, the results showed no such positive effect.

To further understand this result, we chose to conduct a follow up study to know if the prior level of knowledge of the environment and the navigation technique could influence those results. The level of knowledge had a positive influence: the recall rates are significantly better when the environment is known to the user. This confirms previous results showing that IVEs can be successfully exploited as mnemonic devices [9]. Our findings suggest the importance of the level of knowledge of the virtual architectural environment in order to achieve better memorization. However, the higher performances were observed within the egocentric condition, with no navigation and no architectural model in the environment.

The navigation technique showed no influence. The recall performance remained lower in the allocentric condition with the known environment than with the egocentric condition. We do not think that this is due to the cognitive load associated with the navigation technique. If so, it is likely that we would have observed a drop off in the performance for the FN condition. Conversely, we did not observe such an influence.

We think that these results might be associated to high level cognitive phenomena. Recent research showed that allocentric information is likely to be encoded as egocentric representations that are updated as one moves [20]. If it is so, the navigation technique and sensory cues associated with displacement might be of primary importance when it comes to use spatial information to support memorization.

From our results, we derive the following guidelines for building educational VR environments:

- the level of knowledge of the architectural VR environment is a key factor to benefit from spatialization. When using virtual worlds for educational purposes, the environment should be either a virtual world or a virtual representation of a real environment already known by the learner,
- egocentric environments, which do not necessitate large worlds allowing free exploration, are better suited for exploiting spatial information. If interactive and visually rich environments are to be built for educational purposes, they should better not be considered as a way to spatially embed information, but rather as a way to enable actional immersion and motivation through embodiment.

VI. Conclusion

We conducted a study to assess if allocentric spatial cues in IVEs, could be exploited as a mnemonic device in learning activities through the use of MOL. Our results show that a good knowledge of the environment is of importance to that purpose: having prior knowledge of the architectural layout helps within a recall task of lists of items. However, building such rich architectural virtual worlds might not be mandatory for this objective. On the contrary, performances are higher with the use of an egocentric frame of reference, that do not necessitate to build complex virtual worlds.

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