Building a Library in the Mind: Using Virtual Reality and a Memory Palace to Facilitate Remembering Literature

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1 Primary Aims

In this work, we will study the use of virtual reality with a memory enhancement method called "memory palace" to ameliorate remembering the content of scientific literature.

A *memory palace* (or *method of loci*) is a method which uses visualizations and spatial cues as mnemonics to help people quickly and efficiently recall information [1, 2, 3]. This method has two components: 1) a series of intended items that one is going to memorize; 2) the "palace" used to provide a set of loci ("the place where something is situated or occurs" [4]) as the spatial cues. Traditionally, to create a memory palace, one first generates a set of loci based on the physical world, and then connects an intended item to one of the loci by forming an image between the item and any property of the locus. For example, if one of the intended items is the word "apple" and one of the loci is city hall, she could imagine a huge apple on the roof of the city hall. In our work, we will study whether using virtual reality to create the "palace" can be more beneficial for memory enhancement purposes. We will introduce our hypotheses and the experimental setups to test each of the hypotheses as follows.

Hypothesis 1: Using the memory palace method enhances one's memory of scientific literature. We will use two experimental conditions to test this hypothesis.
Control condition: We will first construct a baseline condition, in which we will ask participants to read a series of scientific literature (e.g., publications) on a desktop computer. The participants will receive instructions that they should read the scientific literature carefully in the course of the experiment and they will be asked to recall the content at the end of experiment and again after 24 hours. The instructions don't provide any detail about what method they should use to remember the literature. However, the instructions will provide some restrictions such as they are not allowed to use their notes during the recall sessions.
Mental condition: We will ask the participants to employ the memory palace method using its traditional form, where they will use their imagination to create the "palace". They will first participate in a training session to learn how to use the method. In the main session, for each of the publications, they would use their imagination to connect a publication to a locus (e.g., a chair) in an imaginary room (e.g., a classroom) [5].
We will compare the recall performance of the mental condition to that of the control condition in order to test Hypothesis 1. We expect the recall performance of the mental condition to be significantly higher than that of the control condition.

Hypothesis 2: Using virtual reality with the memory palace method can increase recall performance.
Virtual reality (VR) condition will be used to test this hypothesis. We will use an adapted form of a memory palace, where the participants are able to see a virtual room (i.e., the 3D model of a room) in virtual reality and use the room as their "palace". The participants will see a publication associated with a virtual locus in this artificial room. The artificial room will be built based on a real-world room which the potential participants are familiar with (e.g., a classroom). We expect the recall performance of the virtual reality condition to be at least as good as, if not better than, that of the mental condition.

Hypothesis 3: Using a memorable scene in virtual reality with the memory palace method creates the most effective memory.
Enhanced VR condition and **surreal VR condition** will be used to test this hypothesis. We will test whether the use of a different scene in virtual reality as one's "palace" can improve the recall performance. In the enhanced VR condition, we will further build on top of the VR condition and adapt the scene used to create a more effective "palace" for the participants. For example, we will manipulate the properties of the loci to make them more memorable [6, 7, 8]. In the surreal VR condition, we will use a fantastic scene and select loci from this scene. We expect that the recall performance of the enhanced VR condition or the surreal VR condition to be higher than that of the VR condition.

To summarize, this work aims to demonstrate that using virtual reality with the memory palace method can facilitate remembering the content of scientific literature. For the detail of methods, please see Section 3.

2 Significance

The existing research applying the memory palace method confirmed that this method can improve the memory of certain content; it is not our purpose to merely add one to their number. Our work differs from these existing works in three ways.

First, we aim to enhance semantic memory to assist learning and knowledge generation, in contrast to the improvement in episodic memory in the extant works (Hypothesis 1). In many of the previous studies, participants were asked to use the memory palace method to memorize a word list or an item list [9, 10, 11, 12, 13, 14, 15, 16, 17]. This means is related to a process of forming *episodic memory* [18, 19, 20]. Episodic memory describes that a person being able to remember personally experienced events, as opposed to *semantic memory*, which "registers and stores knowledge about the world in the broadest sense and makes it available for retrieval" [21]. Some the existing works revealed a sense of enhancing semantic memory using the memory palace method. For example, researchers identified the effectiveness of the memory palace method for educational purposes, such as second language learning [22]; the use of mnemonics methods is found to be correlated with a student's GPA in Ruth's work [23]. Empirical observations also confirmed that the memory palace method was employed by a super memorist who can recite π to more than 2^{16} decimal places [24]. However, these researches didn't provide more solid results about how this method used for knowledge retrieval. In our work, we will study the effectiveness of using the memory palace method to improve semantic memory. We use scientific literature as the intended information to capture semantic memory in a remembering task [18, 25].

Second, we will study the effects of using virtual reality on the memory palace method (Hypothesis 2). Starting a mental memory palace is a difficult task which demands more account of cognitive load and attention [9, 12, 17]. This method in its traditional form can hardly be used [9]. Yet previous works used virtual reality to conduct perceptual and cognitive studies [26, 27] for learning [28, 29], education [30], and memory rehabilitation [12]. Drawing inspirations from these works, we believe that the memory palace method can be transmitted to a controlled artificial environment such as a 3D scene generated by modern graphical rendering techniques. Such an artificial environment can be well supported by today's accessible virtual reality devices, which provide a sense of immersion and presence that bridges the gap between the virtual world and the real world. More importantly, virtual reality can furnish a scene that is out of reach in the real world, and in such case, we believe the use of virtual reality can further enhance the recall performance, inviting our third hypothesis about the effects of the environment as follows.

Third, we will evaluate the effects of the environment used in virtual reality on the memory palace method (Hypothesis 3). The traditional form of the memory palace method emphasizes the familiarity of the environment, but the extant works demonstrated that the use of a list of arbitrary loci can be beneficial as well [5, 11] and self-provided visualizations are not necessary [11]. More recent works based on the presence of the loci (a physical environment [9, 12], a 3D virtual room on a desktop [9, 31], virtual reality [26, 32], and augmented reality [17, 33]) continue to ignore the effects of the "palace" used. The researches based on an artificial location predominantly discard the spatial cues in the virtual environment and ignore the potential benefits from using a more memorable environment. In these works, they usually build an arbitrary virtual scene with a low rendering quality, resulting in slightly worse or comparable performance than the other methods used.

The effects of the environment used in virtual reality are likely to be twofold. First, we recognize the rendering quality of the scene might play an important role in a cognitive task. As such, we will try to use a realistic scene in virtual reality with a more satisfying perceptual quality. We won't explicitly test such speculation of using a higher rendering quality, but we will report the empirical observations. Second, we hypothesize that we can further benefit from using virtual reality via introducing properties that don't exits in the real world. For this purpose, we will employ two experimental conditions: one alters reality (enhanced VR condition) and the other uses a fantastic scene (surreal VR condition). In the enhanced VR condition, we will take the advantages from using both familiar cues and memorable features. We will manipulate the loci in the scene based on the properties of a memorable [8, 34] photograph or object [7, 35, 36] to make the loci more effective for enhancing semantic memory. Futhermore, we will also test whether using a totally unfamiliar but surreal scene can be beneficial. We expect that altering the real scene or using a fantastic scene will further enhance the recall performance.

Out of some concern, however, is the similarity between our VR conditions and a possible augmented reality (AR) condition. While the VR condition and the enhanced VR condition can be approximated by augmented reality techniques, using virtual reality is still more beneficial for our tasks for two reasons. First, most of today's AR devices don't fully support our purposes. They usually don't provide stereopsis, making it impossible to alter

the intended loci [1]. Another factor is the hardware memory restrictions which may not allow us to launch a large 3D scene. Second, even regardless of the hardware constraints, VR can be more beneficial by providing a unique enclosed environment. The spatial cues provided by AR techniques substantially rely on the real world, and the changes and distractors in the real world may interfere the remembering and recall performance. For example, if one used her apartment as the "palace". However, she may not be able to access the "palace" as well as its related memory after her re-accommodation. In such a case, the VR technique is likely to retain the environment and restore the memory for a much longer time.

3 Methods

Materials. In all the experimental conditions and the control condition, we will give ten scientific publications to each of the participants. These ten related publications will be selected based on the following criteria: 1) they made different contributions but focus on the same research topic; 2) the topic is not likely to be familiar by a general audience, but does not demand too much background knowledge to understand; 3) the length of the abstracts and the number of propositions in the abstracts are similar. These publications will be reformatted using the same template to remove the factors of format and author names. Depending on the design of the experiment, whether it is a between-subject, within-subject, or mixed design, we will give different sets of literature to each of the participants. The participant will be asked to read the titles and abstracts in a reasonable amount of time. The participant will be told that this is a study of building knowledge about research topics, and that she will be asked to recall these materials at the end of the experiment.

Scenes. The scene in which we will place the scientific literature will be based on a real room that is familiar to most of the potential participants (e.g., a classroom). We will build 3D models based on this physical location. Between the VR condition and the enhanced VR condition, we will modulate the loci used. Corresponding to the ten publications we will select, we will choose ten loci in the scene based on the following criteria: 1) They are on the same open path so that a participant can access to them easily and sequentially; 2) They are of a similar size at a human-scale. In the enhanced VR condition, we will replace the original loci in the room with hypothetically more memorable items based on the previous findings of what objects are memorable [7, 8, 35, 36, 34] and the usage of visual embellishments [39, 40, 41, 42]. In the surreal VR condition, we will consider using a fictional film scene, such as *Alice in Wonderland*. This scene should satisfy the criterion that it is familiar to the potential participants and not too complicated. The loci will be selected based on the same criteria above. We will try to construct the scenes to reach a favourably perceptual quality using a game engine (e.g., Unreal). If it is the case that the game engine is not compatible with our devices, we will implement texture mapping, ambient occlusion, shadow mapping, and global illumination to render the scene.

Measures. We will ask each of the participants to participate in both an immediate recall and a 24-hour recall session. In the immediate recall session, the participant will accomplish the following tasks: 1) recall what publications she read and write down all she can remember for each of the publications; 2) sort the recall materials in the order she read them; 3) write a summary of the research topic based on all the publications she read. Before the 24-hour recall session, the participant will be able to revisit the "palace" (without the given literature). In the 24-hour recall session, the participant will be asked to finish the same three tasks with an additional recognition task, where she will select the ten publications she read and sort them from fifteen publications. The recognition task is inspired by the neuropsychological tests widely used in clinical psychology, such as Hopkin Verbal Learning Test [43] and the Brief Visuospatial Memory Test [44].

Scoring. The scoring system for the recall performance will be based on the measure of *text units* [38, 45, 46, 47] widely used in the field of educational psychology. We will score one's recall based on the number of correct propositions and "macro propositions" [45] (i.e., gist [48, 49]) as well as how wrong the order is. For the recognition task, we will compute the correct answers as well as the rate of true-positives and false-positives. We will also compare the recall performance from the 24-hour session with the immediate session.

Beyond the quantitative measures, we will also look for other qualitative measures. For example, we will record a video and watch how the participants behave differently in different conditions. These observations will provide guidances for further research on using virtual reality to facilitate cognitive tasks.

At the end of the experiment, all the participants will be asked to fill out a short survey, including demographics like age, gender, major, simulator sickness [50], self-reported visuospatial ability, cognitive interests, and whether they follow the instructions closely. For the control condition, they will be asked to report if they use some mnemonics.

[1] Microsoft's HoloLens is believed to launch the holograms, however, the reports by users point out that you can only see holograms at certain distance [37].

Pilot study. We will first run a small pilot study with 3-5 participants for each of the conditions and use the observations and results to guide the further study. The pilot study will be a mixed-design, in which we will prepare two sets of scientific literature. Different sets of literature will be mixed with the experimental conditions based on Graeco-Latin square design. Each of the participants will participate in the control condition, the mental condition, the VR condition, and one of the enhanced VR conditions. If the results from the pilot study are negative towards our hypotheses, we will consider to alter the experiment to a complete within-subject design or focus on the qualitative observations. If the results are favorable for our hypotheses, we will use the same materials to run the full experiment. We will also use the observations in the pilot study to guide the design of the full experiment. If the participants report the experiment is too long, we will consider reducing it to two to three conditions per participant.

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