Title: Spatial orientation and cognitive maps in virtual environments

Theoretical Background

Spatial orientation and the creation of cognitive maps are fundamental processes for human and animal survival[1]. Cognitive maps are essential for optimizing spatial navigation processes and associating actions with specific locations[2]. The ability to create and use the maps has been shown to differentiate across participants. Such processes have been studied using the Spatial Configuration Task (SCT)[3]. It requires participants to adopt an egocentric perspective to recall the surrounding objects after becoming familiar with the environmental space in passive mode. Although successfully employed in traditional screen-set environments, such as video games, it has never been implemented in an immersive virtual environment. Virtual reality (VR) promises a deeper understanding of how cognitive maps are formed[4] by offering an immersive three-dimensional environment enabling individuals to explore and interact with digital objects without needing a physical environment and offering tools to exercise the ability to create cognitive maps in controlled and repeatable contexts.

Aims and Hypotheses

We aim to develop a novel Virtual Spatial Configuration Task (VSCT), a VR-based spatial configuration task designed to assess participants' ability to generate and utilize mental representations of spatial configurations in an active mode that might be useful in research and spatial rehabilitation settings. Building upon the established SCT paradigm, our primary objectives are twofold. First, we aim to create and validate the VSCT to enhance the SCT paradigm's ecological validity and effectiveness by leveraging VR technology's capabilities. Second, we aim to investigate whether the cognitive processes underlying the generation of cognitive maps in VR differ from those in a traditional screen-set environment.

First, we hypothesize to observe a positive cross-correlation between the tasks each participant accomplished. Second, we expect that VR's immersive nature will give participants an advantage in accurately recalling and repositioning memorized objects compared with a non-immersive virtual environment (SCT). Specifically, we expect participants in the VR condition to demonstrate superior accuracy, speed, and efficiency performance in the Cognitive Map Task (CMT – a task for assessing the ability to create spatial maps in a passive allocentric mode)[2] than those who will perform the SCT.

Methods

Participants: To assess the feasibility, validity, and effectiveness of VSCT, we conducted a priori power analysis using G*Power to determine the required sample size. With an effect size (f) of 0.23 (estimated based on a recent similar study using SCT [5]), a significance level (α) of 0.05, and a statistical power of 0.80, the analysis determined a minimum sample size of N = 40. Students aged 18-25 will be recruited from supervisor's courses without incentives or penalties for participation.

Tools: The *Cognitive Map Task* (CMT) assesses participants' landmark usage on a computer-generated city map. They view 1-minute videos with a first-person grid view, randomly spotting 1 or 2 out of 4 landmarks across 20 trials. Afterwards, they must place the landmarks accurately on an overhead grid view. The score corresponds to the number of trials needed to complete the task, indicating spatial mapping skill.

The VR Spatial Configuration Task (VSCT) requires participants to explore scenes in the VR environment while wearing an HTC VR headset. In the training phase, participants will explore scenes (N=20) by viewing three of the five objects, gradually forming mental representations of object triplet positions (i.e., each scene contains three objects). They will have a limited time to study each scene and form associations between object positions, but they can actively turn their head to explore the space. Following training, participants will enter the testing phase of the VSCT. They will be presented with scenes containing two visible objects and tasked with recalling the position of the concealed third object based on the spatial configuration of the triplet learned during training. Accuracy and response times will be recorded to assess task performance.

The *Spatial Configuration Task* (SCT) is similar to the VSCT. Still, participants cannot actively explore the environment by moving within it, as traditional computer screens are used to display the task.

Procedure: Participants will undergo the Santa Barbara Sense of Direction Scale[6], assessing daily-life spatial ability, and an online backward Corsi test[7] for measuring spatial working memory. Only participants with a middle score at the Santa Barbara will be tested since testing people with outlier abilities in creating cognitive maps would show no training improvement. Participants will be assigned to the experimental or control group pseudo-randomly. Initially, all participants will perform the CMT to measure their ability to create spatial cognitive maps at baseline. Then, participants in the experimental group will complete the VSCT, while those in the control group will undergo SCT. In the end, they will perform the CMT again.

Statistical Analysis: A mixed-model ANOVA will be employed to analyze the data derived from the 2x2 factorial design with a Within-Subjects Factor (pre- and post-CMT Scores) and a Between-Subjects Factor (Experimental vs Control group). The backward Corsi task will be used as a covariate.

Commitment to request ethical approval

The protocol will be submitted for approval to the Ethics Committee of Bologna University.

Expected Results and Implications

We expect the VSCT to be a reliable measure of participants' capacity to formulate cognitive maps. Consequently, we hypothesize significant cross-correlations among VSCT, SCT, and SBSOD scores. Furthermore, results are expected to demonstrate the stronger efficacy of the VSCT on participants' ability to generate and utilize mental representations of spatial configurations, thereby validating its utility as a cognitive assessment tool. Participants engaging in the VSCT are expected to exhibit enhanced spatial cognitive performance compared to the control group performing the traditional screen, passive-view version. Indeed, the immersive nature of VR is expected to facilitate the formation and utilization of cognitive maps, leading to improved accuracy and efficiency in spatial memory recall and configuration tasks.

These main outcomes will provide valuable insights into the effectiveness of VR technology for cognitive assessment and its potential applications in stimulating spatial cognitive processes that might benefit cognitive rehabilitation.

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References

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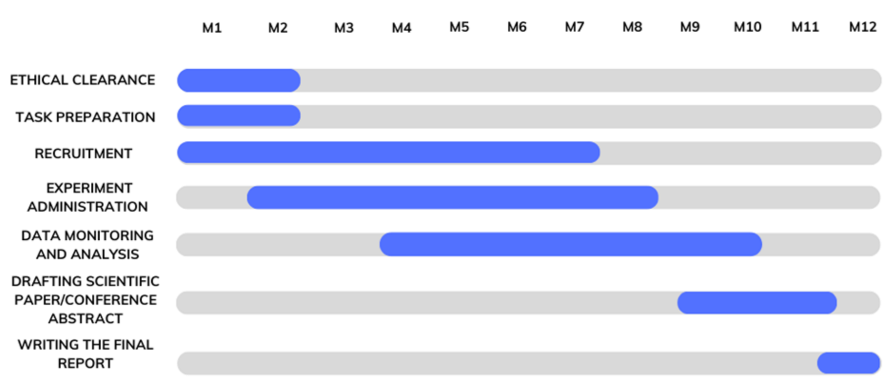
Project activities

- Ethical clearance
- VSCT development
- Recruitment
- Experimental protocol administration
- Continuous data monitoring and analysis
- Drafting scientific paper/conference abstract
- Writing the final report

Training activities

- Deepening the explicit and implicit paradigms for studying cognitive maps
- Refining the statistical analysis
- Participant debriefing of the experiment
- Supervision for scientific writing (papers and conference abstracts)

Timing of activities



Feasibility of the project

CMT is fully available as it is a protocol already used in literature; SCT has been kindly provided thanks to the collaboration with the Neurolab lab at the University of Calgary in Canada. Differently, SCT will be transposed in virtual environments, paying attention to avoid- via pilot testing- VR motion sickness. Participant recruitment through supervisor-led courses and psychology students' training periods ensures access to suitable subjects, streamlining the process without major recruitment hurdles.

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