Spatial and action-related modulating factors of virtual experiences: A mini survey.

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Abstract In recent years, Virtual Reality (VR) has experienced an unprecedented expansion, mostly fostered by a new wave of affordable and reasonably efficient hardware, which has motivated new VR applications in a diversity of fields, from entertainment systems and video games, educational and professional training, to behavioral studies and treatments. However, most of these systems have been created using methodologies which stem from non-VR application development, eluding the salient user embodiment and unique spatial affordances that characterize VEs. A substantial body of evidence from the Cognitive Sciences suggests that self-directed spatial exploration may be closely connected to the formation of episodic memories, composed by knowledge of data objects and their associated spatiotemporal contexts binded as coherent experiences, which in turn trigger recall and connection with other networked elements of memory. The translation of these distinct human cognitive abilities into design criteria for VR may help enhance user experience, engagement and sense of presence, efficiency of interaction and navigation, and overall system usability and application control. Nevertheless, the full set of interacting elements and behaviors, and the magnitude of these relationships are still unclear, thus the need for a literature review that provides insight on previous work on spatial and action-related modulating factors of VR experiences.

Keywords Virtual Reality · Episodic Memory · Spatial Cognition

1 Introduction

The importance of spatial behaviour and self-directed action in memory processes is widely acknowledged in the literature from Cognitive Sciences [1],

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however in VR related studies such components have not been taken sufficiently into account in the design of human-data interaction systems. Norman [2][3] produced some of the earliest work concerning the natural mapping of real world spatial behavior into control interfaces, fostering the idea of enhanced interfaces by use of closely related interaction metaphors. A second important research tradition approached human spatial behavior from the understanding neural dynamics of the Hippocampus during navigation, following the groundbreaking discovery of place cells in the Hippocampus in 1971 [4][5]. Since, the primary function of the hippocampus is thought to be the mental construction of spatial scenes, establishing a shared role in spatial processing and navigation, long term episodic memory and imagination of future events.[6][7] Recently, it has been argued that this distinct set of neural functions becomes activated in the service of self-directed learning behavior.[8][9]

Such findings of context-dependent memory and exploratory behaviors have interesting implications for VEs that have not yet been fully explored. Understanding the uniqueness and potential of VR spatial characteristics for data representation and interaction from an embodied perspective, requires an interdisciplinary effort that integrates knowledge from Cognitive Sciences and Human Computer Interaction (HCI) in order to capture the modulation of experience and memory by contextual and action-related factors.

This integrative framework should act as the connecting link between design solutions and theoretical and empirical work from relevant converging fields, and also help advancing design solutions to fundamental problems related to navigation and interaction efficiency, and user engagement, supported by empirical knowledge on human natural information seeking abilities.

The current review reflects on recent memory studies conducted in Virtual Environments (VE) highlighting overlapping perspectives in spatial learning, navigation and content organization strategies in VR, and the benefits of VR in terms of ecological validity, experimental control and unintrusive acquisition of behavioral responses.

2 Related Work

One of the most relevant characteristics of VR experience is its potential for being indistinguishable from an actual experience, thus allowing the full human cognitive potential to be deployed. Presence, understood as the perceptual illusion of being inside a VE as a non-mediated experience[10][11], is a notion that helps understand and measure this emergent phenomena. In this line, it is widely accepted that richness of sensory information and interactivity are among the fundamental components contributing to Presence.[12]

In a study from 2017, a team led by Makowski[13] presented empirical evidence that aimed at establishing a correlation between participants' sense of Presence and memory of a watched film, in terms of movie facts and scene order, comparing a 3D immersive display and a traditional 2D screen. From the collected data of 244 participants, using a questionnaire based on the ITC-

Sense of Presence Inventory (ITC-SOPI)[14], researchers concluded that the report of a higher sense of presence while watching the movie was related to better factual memory, but not to temporal order memory, regardless of display condition. Also, contrary to some previous assumptions, this study did not find effect of the 3D display on the modulation of presence. Interestingly, in this experimental design, first-person user interactivity is left aside, as well as control of attention toward the stimulus, thus providing evidence from a real world scenario with self-motivated attention and random distractors. However it is questionable the lack of procedural control of time between the end of the test and the moment in which participants respond to the questionnaires.

Extending these real-world resemblance of VEs and the related phenomena of Presence, authors have recently argued that the same spatial mnemonic techniques used in the real world to assist memorization and recall may be translated into VEs. In [15] the research team led by Krokos addresses the possibility to develop VEs as analogical instantiation of a classic mnemonic technique known as The Memory Palace. Memory palaces or method of loci, have been used at least since the 16th century to aid recall by using spatial mental representations and environmental attributes to host studied information objects, allowing the subjective experience of being virtually present in the palace to trigger the recalled items and their associated peers. Although this translation of a classical mnemonic device to a computer system to aid memorization has been previously realized, this article presents a novel approach which examines the effectiveness of stereoscopic experience afforded by modern HMDs in comparison to a desktop display with mouse interaction, and uses images of human faces as the objects to be studied. To this end, the authors developed the software and implemented the commercial hardware solution for 40 participants to be tested with 42 faces each on a HMD condition and a desktop condition treated as independent variables, and the measured accuracy of recall as the dependent variable. The study employed a within-subject trial structure, using a 2 (HMD-condition to desktop-condition vs desktop- condition to HMD-condition) by 2 (Scene 1 vs Scene 2) by 2 (Face Set 1 vs Face Set 2) Latin-square design. The results highlighted a statistically significant effect in recall accuracy and a tendency to more confident answers in the HMD condition. Interestingly, this study also discussed the ongoing search for a balance between experimental control and ecological validity in the design of virtual environments applied to memory studies, and suggested the need for improvements to the technical realization of the present study regarding randomisation of stimuli and interaction modalities, considerations that may be useful for the next iterations.

Similarly, Harman and colleagues presented an article in 2017 [16] that aimed to further confirm interface immersion may translate into enhanced long term episodic memory recall. To this end, they evaluated the differences in recall ability for VR stimuli presented via HMD and desktop monitor, taking into consideration not only the recall ability of participants, but also the task completion time, the amount of environment traversed during exploration, the subjective sense of Presence reported by users via the Witmer and Singer

questionnaire[17], and usability evaluation using the IBM usability satisfaction survey[18]. In this sense, the authors report the lack of existing literature which explored the links between the time spent viewing stimuli and recall performance.

In order to test their hypotheses, a virtual world representing an airport was developed, and the corresponding commercial hardware solution was implemented for both conditions. Participants were placed into a virtual building, and asked to role-play the task of boarding an airplane within a virtual airport, while doing so, describe all the actions carried out within the environment with no time limit. Interestingly, this article reports the novel use of virtual world role-play as trigger for situated context that allows to explore the potential recall in VEs. Following a between-subject design authors analyzed data collected from 31 participants and confirmed that participants using the HMD presented more quantity and detail in recollection than those given the desktop display, and not only reported higher presence than the desktop display condition but also showed a more explorative behavior in VE. However, no statistically significant difference was found in time taken to complete a task or regarding system usability. A distinctive characteristic of this report, is that unlike most experiments conducted in this research field, users in HMD condition rely on the same set of controllers as the desktop conditions, and that interactions with the virtual objects are not afforded by either condition, which limits users' agency. On the other hand, there are a number of recent studies that compare self-directed and guided exploratory behaviors in relation to components of learning [1][19]. For example, Ferguson and colleagues[20] compared in a recent article freedom of choice versus guided learning, in an approach that highlights the need for developing narratives suited to self-directed exploration and interaction abilities. The game "The Chantry" was used in this study, administered to 42 participants via HMD display for a time lapse of 30 minutes for each condition. Then participants were asked to submit a knowledge questionnaire which also addressed the engagement, presence, and cognitive interest of the experience. Responses were analyzed considering the percentage of correct answers on both the factual and spatial questions of the knowledge test. Results found by this study point that user motivation is present in an active exploration behavior, and that increased interaction with an environment supports higher sense of presence. Moreover, showed that participants scored higher on spatial knowledge test in the implicit version, which may be explained by larger, and therefore more rich, amount of spatial information available for the self-directed experience.

Aiming to shed light on the specific conditions of the interactions between spatial navigation and episodic memory, as seen taking effect in The Memory Palace mnemonic technique, a research team led by Plancher published in 2018 an article [21] in which they investigated the role of the verbal and visuospatial mechanisms of working memory on the traces that characterize Episodic Memory such as what, where and when, using a realistic situation afforded by a VE. The authors present a novel model that distinguishes the influence of verbal and visuospatial subcomponents of Working Memory on four different

measures of episodic memories. To this end an interesting research rationale is provided, which underpins the experimental design with corresponding up-to-date knowledge from the cognitive sciences. Notably, researchers developed a virtual urban environment suited for an experimental procedure that tested this model, simulating French buildings and street furniture, and implemented the commercial hardware necessary to allow navigation and adequate audio-visual display of the virtual environment. In order to examine the extent of influence of working memory components on episodic memory formation, 88 participants were randomly allocated to one of three conditions, control group, visuospatial or verbal interference. After driving around the virtual town and memorizing all the elements encountered, along with their spatio temporal contexts, participants were scored in the four different components of Episodic Memory assumed by this study. ANCOVAs were performed on the recall of each score, with each of the three conditions as a between-subjects factor, and the performance in the secondary task as a controlled variable. The results confirmed general hypothesis, that participants performed better when no secondary task was administered. But more precisely, the study presented for the first time evidence that suggest that preventing verbal maintenance through a concurrent task negatively impacts long-term memory of central information, while preventing visuospatial maintenance decreases central, temporal, and binding memory. Overall, a high level of internal and external validity is achieved by this study, using an original model and experimental design supported on VR, suggesting possible generalisations regarding the role of immersive VEs in assisting memory recall.

3 Conclusion

Although current literature shows benefits of self-directed action and spatial organization of stimuli on Episodic memory formation and retrieval, there are a number of challenges concerning the sensory modalities being used for user interaction in VR, as well as a lack of characterization of interaction strategies and memory performance in VR by men and women across ages.

References

1. Chastil, E. and Warren, W. (2013). Active and passive spatial learning in human navigation: Acquisition of survey knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 39, 5 (2013), 1520-1537.
2. Norman D.A. (1986). Cognitive engineering. In: Norman DA, Draper SW (eds). *User-centered system design: new perspectives on human-computer interaction*. Lawrence Erlbaum Associates, Hillsdale, pp 31–62.
3. Norman D.A. (1988). *The design of everyday things*. Basic Books, New York.
4. O’Keefe, J. and Dostrovsky, J. (1971). The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat. *Brain Research*. 34, 1 (1971), 171-175.
5. Redish, A. (1999). *Beyond the cognitive map*. MIT Press.
6. Hassabis, D., Kumaran, D., Vann, S. and Maguire, E. (2007). Patients with hippocampal amnesia cannot imagine new experiences. *Proceedings of the National Academy of Sciences*. 104, 5 (2007), 1726-1731.

7. Dede, A., Wixted, J., Hopkins, R. and Squire, L. (2016). Autobiographical memory, future imagining, and the medial temporal lobe. *Proceedings of the National Academy of Sciences*. 113, 47 (2016), 13474-13479.
8. Voss, J., Gonsalves, B., Federmeier, K., Tranel, D. and Cohen, N. (2010). Hippocampal brain-network coordination during volitional exploratory behavior enhances learning. *Nature Neuroscience*. 14, 1 (2010), 115-120.
9. Voss, J., Warren, D., Gonsalves, B., Federmeier, K., Tranel, D. and Cohen, N. (2011). Spontaneous revisitation during visual exploration as a link among strategic behavior, learning, and the hippocampus. *Proceedings of the National Academy of Sciences*. 108, 31 (2011), E402-E409.
10. Heeter, C. (1992). Being there: the subjective experience of presence. *Presence: Teleop Virtual Environ* 1(2):262-271.
11. Sanchez-Vives, M. V., and Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews - Neuroscience*, 6(4), 332-339.
12. Steuer J (1993) Defining virtual reality: dimensions determining telepresence. *J Commun* 42(4):73-93.
13. Makowski, D., Sperduti, M., Nicolas, S. and Piolino, P. (2017). "Being there" and remembering it: Presence improves memory encoding. *Consciousness and Cognition*. 53, (2017), 194-202.
14. Lessiter, J., Freeman, J., Keogh, E., Davidoff, J. B., & Keogh, E. (2001). A cross-media presence questionnaire: The ITC-sense of presence inventory. *Presence*, 10(3), 282-297.
15. Krokos, E., Plaisant, C., & Varshney, A. (2018). Virtual memory palaces: immersion aids recall. *Virtual Reality*, 23(1), 1-15.
16. Harman, J., Brown, R. and Johnson, D. (2017). Improved Memory Elicitation in Virtual Reality: New Experimental Results and Insights. *Human-Computer Interaction - INTERACT2017: 16th IFIP TC 13 International Conference Proceedings, Part II. (Lecture Notes in Computer Science)*. 10514, (2017), 128-146.
17. Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments*, 7(3), 225-240.
18. Lewis, J. R. (1995). IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for use. *International Journal of HumanComputer Interaction*, 7(1), 57-78.
19. Chrastil, E.R. and Warren, W.H. (2012). Active and passive contributions to spatial learning. *Psychonomic Bulletin and Review*. 19, 1 (2012), 1-23.
20. Ferguson, C., van den Broek, E.L. and van Oostendorp, H. (2020). On the role of interaction mode and story structure in virtual reality serious games. *Computers & Education*. 143, August 2019 (2020), 103671.
21. Plancher, G., Gyselinck, V. and Piolino, P. (2018). The integration of realistic episodic memories relies on different Working Memory processes: Evidence from virtual navigation. *Frontiers in Psychology*. 9, 47.