The Effects of Colored Environmental Surroundings in Virtual Reality

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Abstract

Research has shown that environmental cues affect long-term memory and spatial cognition, but there is still a lack of understanding of the exact characteristics that produce these effects. We conducted a virtual reality (VR) within-subjects repeated measures study on 51 participants to test color congruency. Participants saw and studied 20 objects, then completed object recall and placement tasks in a recall room with a congruent or incongruent color. The objective and subjective data we gathered suggest that congruent color conditions influenced long-term memory and speed for recalled objects. Object size was also shown to influence spatial cognition and long-term memory.

Keywords: Virtual Reality, Spatial Cognition, Long-term Memory, Object Recall, Color, Context-Dependent Memory.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Empirical studies in HCI

1 Introduction

The encoding specificity principle by Tulving and Thomson, asserting that memory retrieval hinges on storage conditions and context cues, illustrates how environmental elements like lighting or color can trigger recollection [7]. This explains phenomena like forgetting an objective upon leaving a room, only to remember when revisiting the space. Research across various settings confirms that consistent environments enhance memory recall in both humans and animals, with recent studies attributing memory context to 'event boundaries' like doorways [4].

Human color perception occurs through the eyes rods and cones for color, detail, and motion, leading to signal transmission to the brain for further analysis [2]. Color significantly impacts survival, perception, and behavior in humans. Research on the interplay between environmental colors and cognitive functions [6], mood [5], and performance [**?**] shows mixed results, with studies indicating that context and color (e.g., blue for high-demand tasks, red for low demand) can significantly affect cognition. Understanding color perception requires delving into perceptual psychology, spanning computational, constructivist, and ecological approaches, each offering insights into how we interpret sensory information and its interplay with memory and cognition.

Godden and Baddeley's work highlighted context-dependent memory in ecologically valid settings [1], while other research explored the impact of colors on restaurant perceptions [8]. Additionally, studies on object recall suggest that color plays a crucial role in strong color-object binding. [3].

Limitations of the previous studies dealt with a minimally controlled physical location, lighting conditions, or partial salience. Our study focuses on how color congruency affects object recall, examining its influence on spatial cognition, memory, and speed, and explores the impact of object size and participant movement within a virtual environment on recall performance. We hypothesize that color congruency will improve recall accuracy and speed, and larger objects will be remembered more easily.

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2 Experimental Design

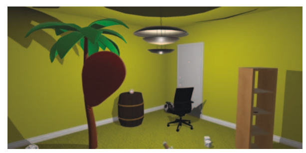

Figure 1: Set of objects participants needed to recall

Figure 2: Recall objects laid out in a 2D array (20 original, 5 novel). The selected items have a transparent white material.

The experimental design for this study utilized high-end computer hardware and a HTC Vive Pro wireless VR setup in a wide-area tracked room to create a detailed virtual environment simulating a standard bedroom, devoid of windows. There were a total of 175 objects. 20 objects were strategically placed in each room to necessitate participant movement for interaction, enhancing the realism and immersion of the virtual space. All participants were given scripted instructions. Sounds and other interaction techniques were used to garner a pleasurable user experience.

To assess the impact of the color congruency conditions on participants, the study design included questionnaires using sliders for self-assessment and toggles for Likert scale questions, covering aspects such as emotion, cybersickness, usability, and workload. The Affective Slider was used to gauge emotional responses to color changes, and the SIM-TLX measured the workload, ensuring the tasks were challenging yet comfortable. The use of the Igroup Presence Questionnaire (IPQ) aimed to measure spatial presence, involvement, and experienced realism, contributing to a comprehensive understanding of participants' experiences within the virtual environment.

3 Procedure

Upon arrival, participants were briefed and consented, then screened for red-green color deficiency using the Ishihara Color Blind Test. After completing a pre-survey, they were introduced to the VR setup and underwent a demo component to familiarize themselves with VR interaction, involving tasks like walking to corners, memorizing objects, and a filler task (to prevent rehearsal of objects). The demo included an object recall phase, where participants identified objects not present in the room, and an object placement phase, where they positioned objects in remembered locations with varying levels of assistance.

The experimental component mirrored the demo in structure but introduced variables such as wall color changes and different objects for each room (7 total). The conditions and sequences were

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randomized to eliminate order effects. Performance metrics were recorded throughout the experimental component. Post-experiment, participants completed questionnaires assessing their experience and strategies and were debriefed on the experiment's goals.

4 Participants

51 (16 M, 35 F) participants completed this within-subjects study. The average age was 19 years old (SD = 4.63 years). 37 participants reported wearing a VR HMD before while 14 never worn a VR HMD before. The participants for this experiment can be generalized as mainly being young, novice VR users.

5 Results and Discussion

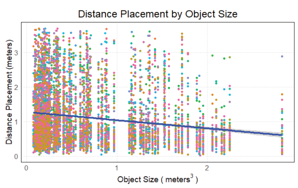

Figure 3: The blue regression line shows the influence of object size on the distance error from the originally located object (main effect).

Figure 4: The difference in the guess time when the study and test room were congruent or incongruent (main effect). Error bars represent a 95% confidence interval.

The study employed linear mixed effects regression models to analyze the data. Color congruency significantly affected the number of items correctly recalled, with participants remembering more items in congruent conditions. However, color congruency did not significantly impact angle or distance placement errors or the time taken to recall items. Object size significantly influenced angle and distance placement errors, indicating larger objects were associated with less error, but did not affect the speed of recall or the number of items remembered. Movement within the VR environment and gender did not significantly impact memory performance. Emotional responses (pleasure and arousal) and comfort levels remained consistent across color congruency conditions, contradicting some previous findings outside of VR contexts.

Technical difficulties, such as breaks in presence (BIP), while not significantly impacting comfort, likely affected the overall VR experience and could have altered participants' attention and engagement with the memory tasks. The challenge of sourcing a large number of high-quality, free-to-use 3D models compatible with Unity meant that some of the objects used in the study were not as realistic as desired, potentially impacting participants' engagement and memory performance.

The study revealed that color congruency enhances memory recall in VR environments, suggesting environmental consistency can be beneficial for memory tasks. Object size influenced spatial placement accuracy but not recall speed or quantity, highlighting its role in spatial memory tasks within VR.

Despite meticulous design efforts, the study faced several limitations. Technical difficulties, such as breaks in presence (BIP), sourcing a large number of high-quality, free-to-use 3D objects, unbalanced conditions, and the number of trials we had participants complete.

6 Conclusion

This study has illuminated the nuanced interplay between various elements of VR environments and their impact on cognitive functions, specifically memory and spatial cognition. We discovered that color congruency within VR environments significantly affects object recall speed and correctness, suggesting that consistent environmental cues can enhance memory retrieval. Contrary to initial hypotheses, color congruency did not significantly impact spatial accuracy in object placement or recall tasks. However, object size itself did affect the speed and placement of objects. The influence of object size on spatial accuracy underscores the importance of object salience in memory tasks within VR.

Our findings suggest a complex relationship between environmental characteristics and cognitive performance in VR, challenging some existing assumptions and highlighting the need for further exploration in this field. The diversity in participants' strategies for recalling object locations emphasizes the individual differences in interacting with VR environments and suggests the potential for personalized VR applications based on cognitive and perceptual preferences.

The implications of this research extend beyond academic inquiry into the practical design and application of VR technologies. As the global workforce ages, with a significant portion of individuals anticipated to be on average 55 years old by 2030, understanding the cognitive impacts of VR becomes increasingly crucial if the future of work is to be in VR. Our findings are particularly relevant given the known degradation of sensory information, including color perception, with age. By understanding the cognitive effects of VR environments, we can create more inclusive, effective, and beneficial virtual experiences for users of all ages.

Future research should build upon our methodology to explore additional environmental characteristics such as size, texture, and brightness, and their relationship to cognitive functions. The study duration could be optimized to enhance participant comfort, especially for standing tasks in VR. Additionally, exploring the opponent process theory in the context of VR could yield insights into performance differences across vision color channels.

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References

[1] D. R. Godden and A. D. Baddeley. Context-dependent memory in two natural environments: On land and underwater. *British Journal of psychology*, 66(3):325–331, 1975.

[2] T. Huff, N. Mahabadi, and P. Tadi. Neuroanatomy, visual cortex. 2021.

[3] T. J. Lloyd-Jones and K. Nakabayashi. Independent effects of colour on object identification and memory. *Quarterly journal of experimental psychology*, 62(2):310–322, 2009.

[4] K. A. Pettijohn, A. N. Thompson, A. K. Tamplin, S. A. Krawietz, and G. A. Radvansky. Event boundaries and memory improvement. *Cognition*, 148:136–144, 2016.

[5] M. A. Read, A. I. Sugawara, and J. A. Brandt. Impact of space and color in the physical environment on preschool children's cooperative behavior. *Environment and Behavior*, 31(3):413–428, 1999.

[6] S. M. Smith and E. Vela. Environmental context-dependent memory: A review and meta-analysis. *Psychonomic bulletin review*, 8:203–220, 2001.

[7] E. Tulving and D. M. Thomson. Encoding specificity and retrieval processes in episodic memory. *Psychological review*, 80(5):352, 1973.

[8] K. Yildirim, A. Akalin-Baskaya, and M. Hidayetoglu. Effects of indoor color on mood and cognitive performance. *Building and Environment*, 42(9):3233–3240, 2007.