Covisit^{VM}: Cross-Reality Virtual Museum Visiting

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Figure 1: (a) Two users covisiting a virtual museum, one in VR and the other in reality using the PC. Screenshots showing the views of (b) the VR user and (c) the PC user interacting with a museum artifact.

Abstract

Virtual Reality Head-Mounted Displays (VR HMDs) are the main ways for users to immerse in a virtual environment and interact with its virtual objects. The experiences of those around the VR HMD users and their effects on HMD users' experiences have not been well studied. In this work, we invite participants to engage in a cross-reality virtual museum visit. With low, medium, and high degrees of non-HMD user involvement, they could incrementally observe, navigate within, and interact with the virtual museum. Our study provides insights into the design of engaging multiuser VR experiences and cross-reality collaborations.

Index Terms: Human-centered computing - Human computer interaction (HCI) - Interaction paradigms - Virtual reality

1 Introduction

In the evolving landscape of Virtual Reality (VR), the integration of VR Head-Mounted Displays (HMDs) into social settings involves not just the primary user but also non-HMD users [2]. The emerging cross-reality technology focuses on the *concurrent* usage of or the *transition* between multiple systems at different points on the reality-virtuality continuum. This study delves into how non-HMD user involvement influences user experience in cross-reality VR contexts, particularly in settings becoming more commonplace as immersive technologies merge into daily activities.

Cross-reality systems have been examined in various contexts [1,5], offering valuable insight into how to use various interfaces to design interactive systems for collaborative activities. We focus on the virtual museum context, where social interactions are intrinsic to the experience. This setting provides an ideal backdrop for examining the effects of non-HMD user involvement on cross-reality experience. Specifically, our study investigates how varying degrees of non-HMD user involvement — observation, navigation, and interaction — impact user experience in virtual museum tours. Our findings showed that a high degree of non-HMD user involvement enhanced the social presence of both VR users and non-HMD users.

This research contributes to understanding the role of non-HMD users around the VR user, offering insights for designing VR experiences in social contexts such as museums and educational settings. It highlights the potential of asymmetric VR experiences, where VR HMDs are used alongside other devices (e.g., PCs, mobile devices), to create engaging collaborative experiences in a variety of cross-reality applications.

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2 System Design and Implementation

We designed a virtual museum environment (see Figure 1). It supports immersive visiting and learning by integrating navigational realism, artifact interactions, and a knowledge-assessment quiz system. Three degrees of non-HMD user involvement were implemented in the system: low, medium, and high. It is manifested through the actions that non-HMD users can perform (see Figure 2). We set a condition of *low* involvement, where users passively observe the VR HMD user's viewpoints mirrored on a screen display. The *medium* involvement condition allowed users to do task 1: environment navigation. They can freely move around in the virtual environment and change their viewing perspectives, with their real-time positions and rotations embodied in a virtual avatar. On top of it, a *high* involvement condition enabled users to do task 2: artifact interaction. They can manipulate the artifact (grab, rotate, and scale) and access their information labels.

Figure 2: Non-HMD user involvement: Low, Medium, and High.

The virtual museum environment was developed in Unity (version 2021.3.6f1c1) and deployed on a Meta Quest 2 VR HMD and a computer equipped with an Intel Core i7-12700K CPU, 32GB RAM, and an NVIDIA GeForce RTX 3080 GPU.

3 User Study

We conducted a within-subjects user study with 24 participants in paired virtual museum tours (14 males, 10 females, aged between 21 and 24, $M = 21.83, SD = 0.96$). The independent variable was the non-HMD user involvement. Users took exploratory tours, during which they could talk to each other and work together on a knowledge check quiz about artifacts within the virtual museum. We measured six dimensions of user experience in virtual museums, including spatial presence, copresence, social presence, engagement, learning, and system usability. The responses were gathered on a five-point Likert scale.

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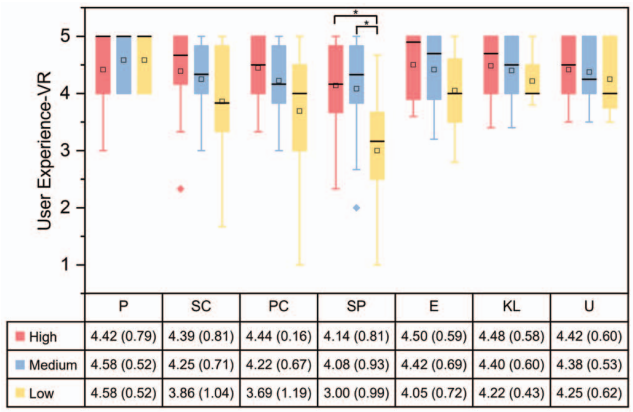
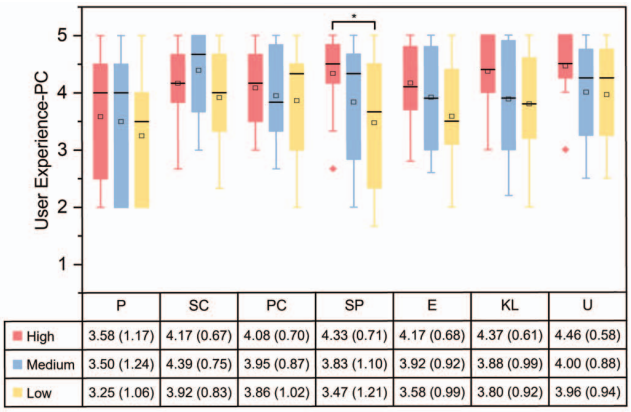


	P	SC	PC	SP	E	KL	U
High	4.42 (0.79)	4.39 (0.81)	4.44 (0.16)	4.14 (0.81)	4.50 (0.59)	4.48 (0.58)	4.42 (0.60)
Medium	4.58 (0.52)	4.25 (0.71)	4.22 (0.67)	4.08 (0.93)	4.42 (0.69)	4.40 (0.60)	4.38 (0.53)
Low	4.58 (0.52)	3.86 (1.04)	3.69 (1.19)	3.00 (0.99)	4.05 (0.72)	4.22 (0.43)	4.25 (0.62)



	P	SC	PC	SP	E	KL	U
High	3.58 (1.17)	4.17 (0.67)	4.08 (0.70)	4.33 (0.71)	4.17 (0.68)	4.37 (0.61)	4.46 (0.58)
Medium	3.50 (1.24)	4.39 (0.75)	3.95 (0.87)	3.83 (1.10)	3.92 (0.92)	3.88 (0.99)	4.00 (0.88)
Low	3.25 (1.06)	3.92 (0.83)	3.86 (1.02)	3.47 (1.21)	3.58 (0.99)	3.80 (0.92)	3.96 (0.94)

Figure 3: Box-plots and the means (with standard deviations) showing user experience of VR (left) and PC (right) users. P = Presence, SC = Self-reported copresence, PC = Perceived other's copresence, SP = Social presence, E = Engagement, KL = Knowledge/Learning, U = Usability.

4 Results

A one-way repeated measure ANOVA showed a significant difference in VR HMD users' perceived social presence, $F(2,33) = 5.934, p = .006, \eta^2 = .265$. Post hoc tests revealed that VR users perceived significantly greater social presence with high ($p = .012$) and medium ($p = .017$) non-HMD user involvement than low involvement. Similarly, there was a significant difference in non-HMD users' perceived social presence, $\chi^2(2) = 7.086, p = .029, W = .295$. Specifically, non-HMD users' perceived significantly greater social presence with high involvement than low involvement ($p = .038$). We did not observe any significant effect of non-HMD user involvement on users' perceived spatial presence, copresence, engagement, learning, or usability. Detailed results are shown in Figure 3.

Comparing VR and PC users' perceived experiences, the results showed that they had similar experiences for the three involvement conditions, except that the perceived presence was significantly greater for VR HMD than non-HMD for the low ($t = 3.126, p = .002$) and medium ($t = 2.257, p = .033$) involvement conditions. No statistically significant differences were found in other comparisons.

5 Discussion and Conclusion

This study examined how non-HMD user involvement affects user experience in cross-reality museum visiting. We found that the degree of non-HMD user involvement plays a significant role in the perceived social presence in virtual museum visiting. This was found significant for both VR HMD users and non-HMD users. Particularly, navigation and artifact interactions allowed in a high involvement condition contributed to the greater perceived social presence. Based on the measure of social presence [3], these results suggest that increased non-HMD user involvement can enhance VR users' sense of connection and interaction with other users. This indicates that, for VR users to achieve a high social presence in a virtual museum visiting experience, a medium degree of non-HMD user involvement is required. Specifically, this involves including virtual avatars and enabling non-HMD users to move around in the environment. In a parallel vein, for non-HMD users, the findings imply that a high degree of involvement, characterized by the ability to interact with museum artifacts, is necessary to experience a similar level of social presence. However, we did not find significant effects of it on spatial presence or copresence.

While no significant differences were observed in the two dimensions of museum experience (Engagement and Knowledge/Learning), a similar trend emerged in the results of both VR and PC user experience: the degree of museum experience increased as the degree of involvement grew. This trend suggests that higher degrees of involvement tend to contribute positively to the museum experience, yet it is important to recognize that other factors also play a role in shaping the experience. This observation aligns with previous research [4], which discussed factors such as knowledge, interests, and motivation as key contributors to museum experiences.

To conclude, our study showed that the higher the non-HMD user involvement, the greater the perceived social presence in the virtual museum visiting experience. In addition, users reported a comparable user experience for the high degree of non-HMD user involvement, regardless of whether they wore a VR HMD or not. This implies that non-HMD devices such as PCs could serve as a viable alternative to engage a broader audience in co-visiting virtual museums. Future research could expand the scope of research to other cross-reality contexts, which would be beneficial for understanding the broader implications of these findings.

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