https://doi.org/10.2352/EI.2024.36.2.SDA-353

Comparative Analysis of User Experience in Virtual Reality (VR) and Mixed Reality (MR) Systems Using Eye-Tracking Measurements

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Abstract

This study evaluates user experiences in Virtual Reality (VR) and Mixed Reality (MR) systems during task-based interactions. Three experimental conditions were examined: MR (Physical), MR (CG), and VR. Subjective and objective indices were used to assess user performance and experience. The results demonstrated significant differences among conditions, with MR (Physical) consistently outperforming MR (CG) and VR in various aspects. Eye-tracking data revealed that users spent less time observing physical objects in the MR (Physical) condition, primarily relying on virtual objects for task guidance. Conversely, in conditions with a higher proportion of CG content, users spent more time observing objects but reported increased discomfort due to delays. These findings suggest that the ratio of virtual to physical objects significantly impacts user experience and performance. This research provides valuable insights into improving user experiences in VR and MR systems, with potential applications across various domains.

Introduction

Virtual Reality (VR) and Mixed Reality (MR) systems have become increasingly prevalent across various fields. In recent years, XR headsets equipped with cameras capable of capturing the external environment have been developed, enabling headsets that support both VR and MR/AR environments to be commercially available. It is anticipated that content seamlessly enjoying VR and MR experiences using such headsets will be developed in the future.

Our research has focused on exploring user experiences in VR and MR environments, with a particular emphasis on investigating discomfort[1]. In studying discomfort differences between VR and MR, we observed that sensations such as dizziness and instability are more quickly perceived in MR environments as discomfort. However, due to the differing ratios of physical and virtual space in VR and MR[2], qualitative differences in user experiences are expected, though specific characteristics have not been clearly identified. Therefore, this study aims to compare the qualitative user experiences during tasks in VR and MR environments to elucidate their respective characteristics.

Method

Task

This experiment employed a three-dimensional puzzle as a task that could be continuously performed in both VR and MR. The puzzle involved assembling seven differently colored and shaped blocks into a 3x3 cube. Participants engaged in the assembly task by

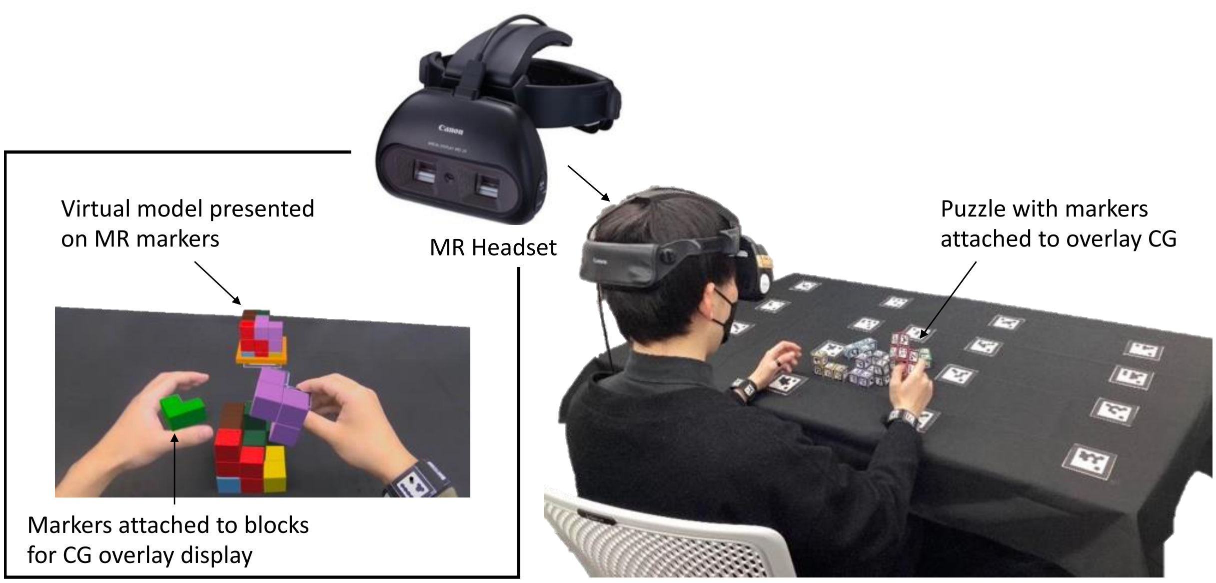

Figure 1. *Layout of experiment*

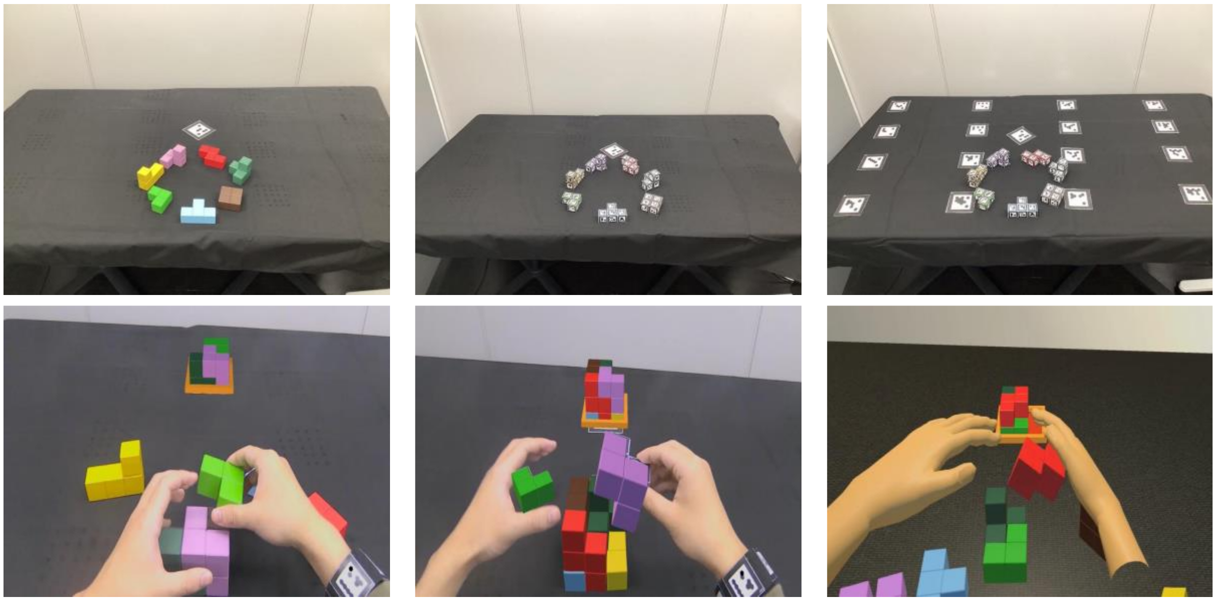

Figure 2. *Experimental Conditions*

repeating the processes of observation and assembly. During observation, each block assembly step was presented through computer graphics (CG), while during assembly, participants stacked the blocks according to the presented assembly steps. Each participant performed three trials of assembling the 3x3 cube.

Conditions

Three experimental conditions were prepared, as illustrated in Figure 2:

- MR (Physical) Condition: Only CG representing assembly steps was displayed as virtual objects.
- MR (CG) Condition: In addition to assembly steps, CG was overlaid on physical blocks, making them appear as virtual objects. Target markers were attached to the physical blocks for CG overlay. As the markers were covered by CG, they were not visible from the headset.
- VR Condition: The entire experimental environment was composed of virtual objects. In the physical space, target markers were attached to the table and physical blocks, and marker bands were worn on participants' wrists for tracking hand models. Surrounding environments, physical blocks, hands, and everything else were displayed as CG based on the target markers. As with the MR conditions, the markers were not visible from the headset.

The headset used in the experiment was a video see-through type (MD-20, CANON).

Measurements

As subjective index, participants provided ratings using a 5-point scale for each trial for the following aspects: "Usability of the blocks," "Realism," "Ease of distance perception," and "Discomfort such as fatigue or motion sickness."A comprehensive interview was conducted after all trials.

As objective index, task trial time and eye gaze were measured. Eye gaze was measured using eye-tracking glasses (Pupil Invisible, Pupil Lab).

Procedure

Participants were 12 university students with normal visual acuity. First, the purpose and method of the experiment were explained, and their consent was gained. Participants wore marker bands on their wrists, measurement devices, and headsets. The interpupillary distance was measured and adjusted to the image clearly. Practice trials were conducted for each condition to ensure smooth task operations. Trials were then randomly conducted for each presented condition.

Results

Subjective index

Figure 3 shows the evaluation results for usability. Multiple comparison tests revealed significant differences ($p<.05$) among all conditions. Regarding realism, ease of distance perception, and discomfort, significant differences ($p<.05$) were observed between MR (Physical) and MR (CG) conditions, as well as between MR (Physical) and VR conditions, with MR (Physical) condition receiving higher ratings in all conditions (Figure 4).

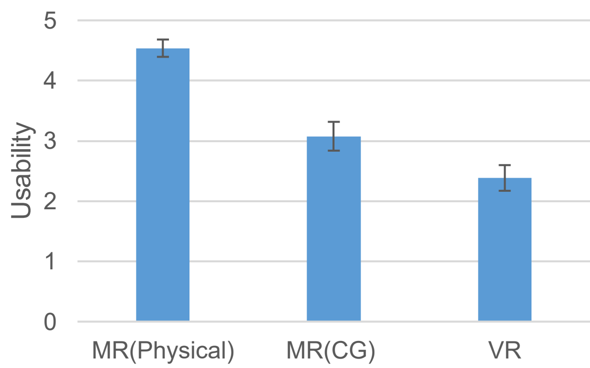

Figure 3. *Result of usability score*

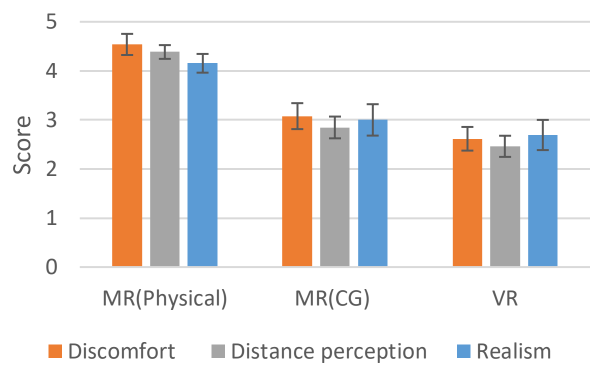

Figure 4. *Result of subjective index (discomfort, distance perception, realism)*

Objective index

In trial time, multiple comparison tests revealed significant differences ($p<.01$) between MR (Physical) and MR (CG) conditions, as well as between MR (Physical) and VR conditions. MR (Physical) condition exhibited the shortest trial time (Figure 5).

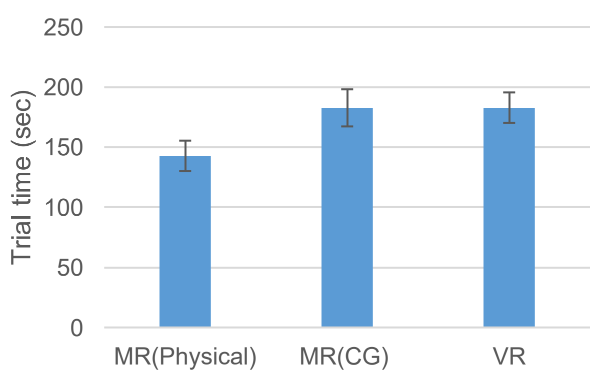

Figure 5. *Result of Trial time*

For eye gaze measurements, three segments were defined: virtual objects serving as guides, physical blocks during assembly, and assembled blocks. The proportion of gaze time for each segment in relation to trial time was calculated (Figure 6). Results of the analysis of variance considering experimental conditions and segments showed a significant interaction ($p<.01$). Post-hoc tests indicated a significantly higher proportion of observing the virtual object in MR (Physical) condition ($p<.01$), with significant differences ($p<.01$) observed between MR (Physical) and MR (CG) conditions, as well as between MR (Physical) and VR conditions for all segments.

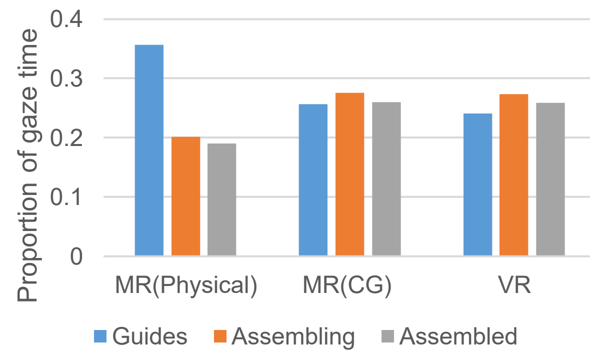

Figure 6. *Result of gaze duration*

Discussion

From the result of usability, the MR (Physical) condition received the highest ratings. Furthermore, in terms of trial time, the MR (Physical) condition exhibited the shortest duration. This outcome aligns with participant interviews, where all participants identified the MR (Physical) condition as the most preferable. The shorter trial time and reduced time spent observing physical objects suggest that the tangibility of the manipulated objects influences the results.

From eye gaze measurements, it was observed that the proportion of observing assembling or assembled blocks increased in the MR (CG) and VR conditions. In interviews, participants highlighted discomfort due to delays in overlaying CG, which may have contributed to the increased observation time of blocks assembling and the assembled block group.

Conclusion

This study compared and examined user experiences during tasks using VR and MR, utilizing subjective and objective metrics. The results suggest that differences in the proportion of virtual objects surrounding users contribute to variations in user experiences. Specifically:

- Lower CG ratios correlated with higher performance and quality of user experiences. In MR (Physical) condition, participants spent less time observing physical objects and mainly used virtual objects to confirm the next instructions.
- Higher CG ratios correlated with increased observation time for blocks being manipulated and the assembled block group. Insights from introspective reports also indicated a rise in discomfort due to delays.

These suggest that the operability of CG objects improves as the ratio of CG decreases. This trend is considered foundational knowledge for UX design in MR. Future research aims to distinguish whether differences in user experience stem from physical-virtual ratios or delay-related discomfort, further advancing the qualitative enhancement of VR and MR applications.

References

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