Study on the Impact of Frame Rate and Resolution on Cognitive Load in Virtual Reality

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Figure 1: Resolution Comparison for a VR Experience

Abstract

Extended Reality (XR) technology holds incredible potential to transform the world. However, this technology is not without it's faults. People often experience an excessive cognitive load when using XR devices, leading to decreased task performance and increased discomfort. Exessive cognitive load can act as a barrier for XR adoption, as it makes several of the use cases for XR less viable. Business owners are less likely to conduct workplace training through XR if it disrupts workers' ability to think effectively while on the job. School systems have no motivation to integrate XR into teaching if it disrupts students' ability to learn. To address these issues, this review covers strategies to mitigate cognitive load in XR.

CCS Concepts

• **Human-centered computing** → **Virtual reality**; **Mixed / augmented reality**; *User studies*; • **General and reference** → *Surveys and overviews*; *Empirical studies.*

Keywords

Virtual reality, Cognitive load, Extended reality, Human computer interaction, Simulation, Visual effects, Rendering(computer graphics), Graphics

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1 Background Study

This background study will be showcasing the necessary research that went into this study. Exploring the fields that are coming together in this study specifically looking at the field of extended reality, information on frame rate and resolution, and cognitive load.

1.1 Extended Reality

Extended Reality (XR) has gained increased usage across various mediums, including gaming, health industry, and education. Specifically involving Virtual Reality (VR), it enables users to engage with digital content in ways that closely resemble real-world experiences. However, the quality of these experiences is dependent on technical factors such as frame rate and resolution, which can impact user perception, performance, and cognitive load.

In Criollo-C et al.'s (2024) article, they discuss the idea that Extended Reality has transformed the educational model. Explaining that it has allowed students to have a more immersive education experience, but there could be negative effects that should not be overlooked. Using a VR application, they test to see how learning in XR affects students' mental workload.[5]

1.2 Frame Rate and Resolution

Frame rate, with the standard unit of measure being frames per second (FPS), determines the perceived smoothness of motion in a VR environment. High frame rates (e.g., 60 FPS or higher) are generally associated with improved visual fluidity and reduced motion sickness, while lower frame rates can cause user discomfort.

In Wang et al.'s (2023) article, the bring up the fact that the demand for higher frame rate has been growing, but that there is constant choice between using hardware that can support higher frame rate that cost more than other trade offs. They use their study to explore how frame rates such as 60 fps, 90 fps, 120 fps, and 180 fps affect the user.[9]

Resolution, defined by the number of pixels displayed in the VR headset, affects the visual clarity of virtual environments. Higher resolution enhances visual detail and reduces pixelation, contributing to a more immersive experience for users. Conversely, lower resolution can make objects appear blurry, potentially increasing the cognitive load of users.

In Wang et al.'s (2022) article, the team turned their focus on video resolution specifically in VR head-mounted displays (HMDs). They explore this topic to determine what are the benefits of the user's experience when dealing with higher resolution in a VR game.[8]

1.3 Cognitive Load

Understanding the impact of these technical factors on cognitive load is important, particularly for applications requiring prolonged focus. Cognitive load refers to the mental effort needed to process information and perform a task. One resource that is widely used is the subjective assessment tool known as the NASA Task Load Index (NASA-TLX), which is used to help measure the cognitive workload of the users.[2]

In Zhi and Wu's (2023) article, they analyzed the findings of previous studies about the implementation of XR on learning languages. Instead of using the NASA-TLX, they used a different model known as the Cognitive Affective Model of Immersive Learning (CAMIL). This model focuses on six affective and cognitive factors that play a role in XR learning; these include interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation.[10]

While cognitive load focuses on the mental effort users need to perform a task, it is important to look into how cognitive load can affect the user in other ways. In lustig et al.'s study, they investigate how cognitive load impacts head-hand coordination by using a VR-based adaptation of the Color Trails Test (VR-CTT). In their research they explored the interaction between cognitive processing and the user's motor function.[6]

In this study, we investigate how variations in frame rate and resolution affect cognitive load in a VR escape room scenario. By adjusting these factors and evaluating user responses using the NASA-TLX, we aim to gain more insight into the relationship between VR system performance and user cognitive load.

2 Introduction

Extended Reality (XR) is a term that encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR). XR has grown in popularity as the technology has matured, and it is likely to continue that path of growth for the foreseen future. In creating interactive and immersive virtual environments, XR allows us to connect to otherwise abstract ideas that would, under normal circumstances, seem completely alien. It is a technology that allows us to step into a different life and learn from it. That is why it is no surprise that it has seen its largest commercial use in training and education[1]. Whether teaching a fast food worker how to operate a fryer or putting a soldier through high-intensity scenarios, it is much safer to give this type of education through a low-risk virtual simulation.

Cognitive load is the mental effort needed to process information and complete tasks. If someone feels like it is more difficult to process information than under standard conditions, they would be under cognitive load. A high cognitive load can lead to increased errors when performing tasks, which makes it a significant hurdle to overcome, as it runs counter to many of the uses of XR[3]. There are many theories on the causes of cognitive load, and how it could be mitigated or prevented. One of the most widely accepted reasons being the human brain's limited working memory. The part of memory that humans use to process information and think actively is limited to a small amount of information at a time, and having a large amount of information presented or sufficiently complex information can overwhelm this smaller capacity.

Cognitive load is broken into three primary types; intrinsic load, the inherent complexity of the information or task; extraneous load, the unnecessary or distracting elements that increase mental effort without factoring into the learning process; and germane load, the mental effort that is required to learn something and transfer it from working memory to long term memory. While intrinsic load and germane load are difficult to mitigate or reduce, extraneous load is often reducible through proper design of materials. [7]

3 Method

This study will investigate how changes in frame rate and resolution within a VR environment affect user cognitive load. The study will be utilizing the HTX Vive Focus Vision VR headset, and will be utilizing a free Unity-based VR escape room as the VR environment. Surveys will be given to the user both before and after the VR experience, and a post-experience NASA-TLX assessment will be given. Participants will be recruited from a population of university

students. Each participant will be provided with informed consent prior to the study.

The study will follow a within-subjects design where each participant will experience varying frame rates and resolutions. Frame rates will be adjusted across three levels: 90 fps, 60 fps[9], and 30 fps[4]. Resolution will be adjusted across three levels: 1080p, 720p, and 480p. Frame rate and resolution changes will occur independently, to ensure that the impact of each factor is measured without interference from the other.

Participants will first be given a brief overview on how the test will be going. After the overview, they will proceed with the VR escape room task, during which the frame rate and resolution will be altered. Upon the completion of each section per alteration to the frame rate and resolution, before beginning the next part, the participant will be given the NASA-TLX to complete. This process will be repeated until all conditions are tested.

References

[1] Ahmed Alnagrat, Rizalafande Che Ismail, Syed Zulkarnain Syed Idrus, and Rawad Mansour Abdulhafith Alfaqi. 2022. A review of extended reality (XR) technologies in the future of human education: Current trend and future opportunity. *Journal of Human Centered Technology* 1, 2 (2022), 81–96.

[2] Olivier Augereau, Gabriel Brocheton, and Pedro Paulo Do Prado Neto. 2022. An Open Platform for Research about Cognitive Load in Virtual Reality. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. IEEE, 54–55.

[3] Nikitha Donekal Chandrashekar. 2024. [DC] Understanding the Impact of the Fidelity of Multimodal Interactions in XR based Training Simulators on Cognitive Load. In *2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. IEEE, 1116–1117.

[4] Mark Claypool, Kajal Claypool, and Feissal Damaa. 2006. The effects of frame rate and resolution on users playing first person shooter games. In *Multimedia computing and networking 2006*, Vol. 6071. SPIE, 607101.

[5] Santiago Criollo-C, Jose Cerezo, Andrea Guerrero-Arias, Agariadne Dwingo Samala, Soha Rawas, and Sergio Luján-Mora. 2024. Analysis of the mental workload associated with the use of virtual reality technology as support in the higher educational model. *IEEE Access* (2024).

[6] Adi Lustig, Meytal Wilf, Israel Dudkiewicz, and Meir Plotnik. 2023. Higher cognitive load interferes with head-hand coordination: virtual reality-based study. *Scientific Reports* 13, 1 (2023), 17632.

[7] Alexis D Souchet, Stéphanie Philippe, Domitile Lourdeaux, and Laure Leroy. 2022. Measuring visual fatigue and cognitive load via eye tracking while learning with virtual reality head-mounted displays: A review. *International Journal of Human–Computer Interaction* 38, 9 (2022), 801–824.

[8] Jialin Wang, Rongkai Shi, Zehui Xiao, Xueying Qin, and Hai-Ning Liang. 2022. Effect of render resolution on gameplay experience, performance, and simulator sickness in virtual reality games. *Proceedings of the ACM on Computer Graphics and Interactive Techniques* 5, 1 (2022), 1–15.

[9] Jialin Wang, Rongkai Shi, Wenxuan Zheng, Weijie Xie, Dominic Kao, and Hai-Ning Liang. 2023. Effect of frame rate on user experience, performance, and simulator sickness in virtual reality. *IEEE Transactions on Visualization and Computer Graphics* 29, 5 (2023), 2478–2488.

[10] Yuying Zhi and Lihuan Wu. 2023. Extended reality in language learning: A cognitive affective model of immersive learning perspective. *Frontiers in Psychology* 14 (2023), 1109025.

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