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# Reading in Virtual Reality: Comparing User Reading Preferences Between the Varjo VR-2 Pro and Meta Quest 2 Virtual Reality Headsets

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Tiivistelmä — Referat — Abstract

This thesis investigates how different virtual reality (VR) headsets, specifically the Varjo VR-2 Pro and Meta Quest 2, impact the reading experience, with a focus on user preferences, perceived workload, and reading speed. Many Virtual Reality applications include reading text. However, the usability and comfort of reading in VR environments remain underexplored, especially when considering differences in display techologies.

The study employed an user experiment in which participants read texts while adjusting settings for text height, width, and font size in VR. Key factors, including user comfort, perceived workload, and reading speed, were measured and compared across the two headsets. Additionally, eye-tracking data from the Varjo VR-2 Pro was used to measure reading speed.

The findings reveal significant differences between the two headsets, with users preferring smaller text panels on the higher-resolution Varjo VR-2 Pro compared to the Meta Quest 2. While text panel dimensions affected user comfort and preferences, they had minimal impact on reading speed, which showed weak correlations with these display characteristics. The study also found that the Varjo VR-2 Pro introduced a higher perceived workload due to its greater weight and difficulties in hand-tracking, despite its superior visual fidelity.

These results highlight the importance of taking display characteristics into account when designing personalised VR interfaces. This research contributes to the growing body of knowledge on human-computer interaction in virtual environments and provides practical insights for the design of VR systems optimized for reading tasks.

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# 1 Introduction

## 1.1 Background and Context

Virtual reality (VR) has rapidly evolved from an experimental technology to a widely-used tool in fields ranging from entertainment and gaming to professional training, education, and healthcare. One area that is receiving growing attention is the application of VR in creating immersive reading experiences. VR offers the potential to revolutionize how users consume and interact with digital content, including text, by providing an immersive environment that could enhance focus, reduce distractions, and personalize the reading experience.

However, despite these potential advantages, there remain significant challenges related to the usability and effectiveness of reading in VR environments. Key factors such as display resolution, field of view, user comfort, and the ability to read text for extended periods are influenced by both hardware and software. The way text is displayed in VR, such as the size of the text panels and font, directly impacts the readability and comfort for users. This makes understanding the influence of different VR headsets on the reading experience critical for improving the technology's application in education and other reading-intensive environments.

## 1.2 Problem Statement

While prior research has explored various aspects of VR headsets, such as user immersion and comfort in virtual environments, there has been relatively little focus on understanding how different VR headsets compare in terms of enabling effective reading. Most importantly, the role of hardware, such as display characteristics, eye-tracking capabilities, and resolution, in shaping the reading experience has not been thoroughly investigated. This study addresses the gap by comparing two widely-used headsets, the Varjo VR-2 Pro and the Meta Quest 2, in terms of their ability to facilitate comfortable and efficient reading.

The specific problem addressed in this thesis is the lack of understanding of how hardware differences between the Varjo VR-2 Pro and the Meta Quest 2 impact users' reading performance and experience in VR.

## 1.3 Research Objectives

The main objective of this study is to compare the Varjo VR-2 Pro and Meta Quest 2 headsets in terms of their ability to support reading tasks. This will involve examining various aspects of the reading experience, including reading speed, user comfort, and preferences for text panel adjustments. By analyzing these factors, the study aims to:

- Investigate the impact of hardware characteristics (resolution, field of view, refresh rate) on reading performance in VR.
- Assess user preferences for text display settings (such as font size and panel size) across the two headsets.
- Determine the factors affecting reading speed and comfort in VR, and identify whether these factors vary between headsets.

## 1.4 Research Questions

This study addresses the following research questions (RQs), which investigate various aspects of the reading experience in virtual reality using different headsets:

- **RQ1**: How does vr display technology impact the optimal settings for the reading experience?
- **RQ2**: How does the choice of VR headset impact perceived workload?
- **RQ3**: What physical attributes of each VR headset impact the reading experience?
- **RQ4**: How do display characteristics (such as height, width, and font size) influence reading speed in virtual reality?

These research questions guide the analysis and interpretation of the findings in this study. In subsequent chapters, these questions are referred to in the discussion of results and conclusions.

## 1.5 Significance of the Study

This research is significant because it provides new insights into the use of VR for reading tasks, an area that is likely to grow in importance as VR technology becomes more mainstream in education and professional settings. Understanding the relationship between hardware characteristics and reading performance could help developers design more user-friendly VR systems optimized for reading. Additionally, by comparing two popular VR headsets, this study provides practical guidance for users and organizations looking to adopt VR for reading-intensive applications.

Moreover, this research contributes to the broader field of human-computer interaction (HCI) by examining how hardware and software influence the user experience in immersive environments. The findings could inform future research on optimizing VR interfaces for a wide range of tasks beyond reading, such as writing, learning, and collaboration in virtual spaces.

Results of this study were published at CHI'24 [16].

## 1.6 Thesis Structure

The thesis is organized into the following chapters:

- **Chapter 2: Literature Review**: This chapter reviews the existing literature on virtual reality, human-computer interaction, and the use of VR for reading tasks. It will highlight key studies related to VR display characteristics, user comfort, and performance in virtual environments.
- **Chapter 3: Methods**: This chapter outlines the methodology used to conduct the study, including a detailed description of the experimental setup, the hardware and software used, and the data collection and analysis techniques employed.
- **Chapter 4: Results**: This chapter presents the results of the study, including the analysis of reading speed, user preferences, and comfort across the two headsets.
- **Chapter 5: Discussion**: In this chapter, the findings are discussed in the context of the existing literature, and the implications for the future use of VR in reading tasks are explored.

- **Chapter 6: Conclusion**: The final chapter summarizes the key findings, outlines the limitations of the study, and suggests directions for future research.

# 2 Related work

The related work chapter aims to provide a comprehensive review and analysis of existing research related to virtual reality (VR) and reading on computer screens. While our focus is specifically on reading in VR, examining past literature on reading from traditional computer screens and print can provide valuable context and allow comparisons across different mediums.

This chapter is divided into three main sections: (1) reading in VR/AR, (2) general VR research, and (3) reading on computer screens. Each section provides a detailed examination of relevant research findings.

## 2.1 A quick history of VR

First, we provide a brief history of VR, covering key milestones and developments from its early conceptualization to modern-day advancements, before diving deeper into recent studies. This historical overview helps establish the technological context and highlights the evolution that has shaped the current state of VR research and applications.

### 2.1.1 "Pre-history"

Sir Charles Wheatstone described stereopsis in 1838. He explained the human binocular vision and constructed the first stereoscope, demonstrating how the brain combines two images from different points (each eye) to create a sense of depth and immersion [12].

### 2.1.2 First VR machines

In 1956, cinematographer Morton Heilig created the first VR machine, called the Sensorama, which was a large booth that could fit up to four people. It stimulated multiple senses, including 3D video, audio, vibrations, smell, and atmospheric effects like wind [12]. In 1960, Heilig patented the first head-mounted stereoscopic VR machine, though it lacked motion tracking. The first head-mounted display (HMD) with motion tracking, called the Headsight, was created by two Philco Corporation engineers in 1961 for military purposes.

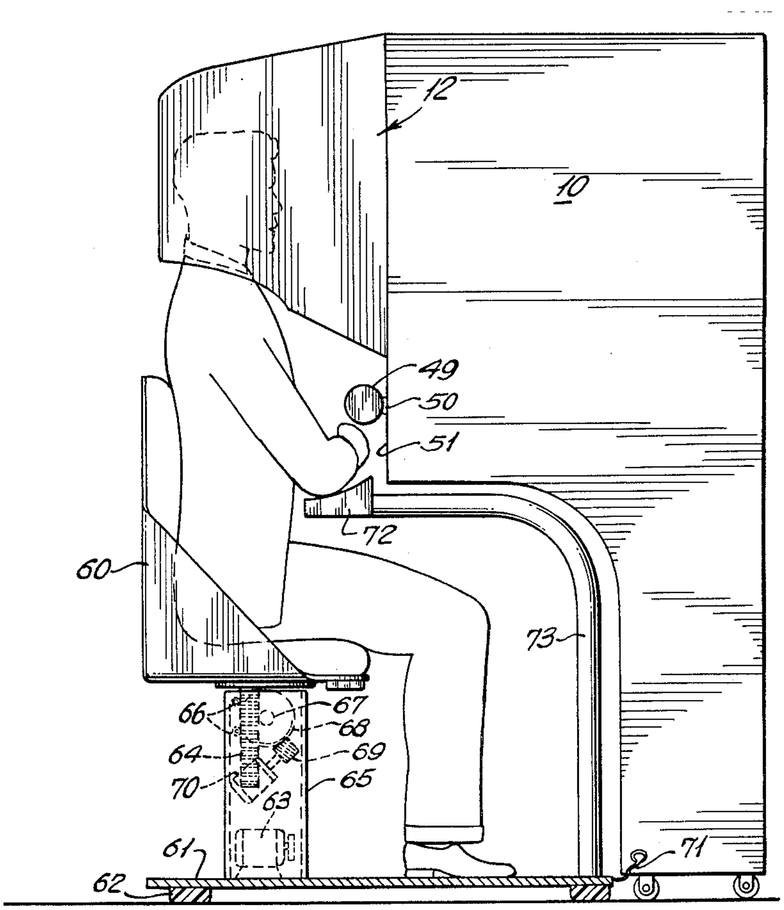


**Figure 2.1:** Sensorama. (2022, September 21). In Wikipedia. https://en.wikipedia.org/wiki/Sensorama (Public Domain)

It was not used for virtual reality but instead paired with a camera that followed head movements. [12].

### 2.1.3 Sutherland, visionary in the 1960s

In the 1960s, Ivan Sutherland, often referred to as the "Father of Computer Graphics," laid the foundation for VR with his groundbreaking paper, "The Ultimate Display" (1965) [35]. Sutherland's visionary ideas and concepts set the stage for further exploration into creating immersive virtual environments.

In the paper, Sutherland discusses the limitations of traditional displays and argues that humans should be able to communicate with computers more naturally and intuitively. He proposes the concept of an "ultimate display" that can provide a rich and immersive virtual reality experience. He envisions a system that can generate immersive three-dimensional pictures. He proposes the idea of a head-mounted display accommodated with hand-tracking gloves for interaction with the system.

However, Sunderland's vision wasn't restricted to head-mounted displays. Per his own words:

> "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming, such a display could literally be the Wonderland into which Alice walked." [35]

In 1966, Sutherland and Bob Sproull created the first virtual reality HMD, named The Sword of Damocles. It had head-tracking and was connected to a computer, creating a simple virtual environment with primitive wire-frame shapes. However, due to the head-tracking, the perspective changed when the user moved their head so we can argue that this, indeed, was the first virtual reality, motion-tracking HMD.

### 2.1.4 Commercialization in the 1980s

In the 1980s, Jaron Lanier, a computer scientist and entrepreneur, founded VPL Research, a company that developed some of the earliest commercial VR systems. These HMDs allowed users to view computer-generated worlds by wearing a head-tracking HMD paired with motion-tracking gloves for hand-tracking, generating more immersive interactions.

### 2.1.5 Arcade gaming in the 1990s

In 1990, Jonathan Waldern introduced Virtuality, a virtual reality arcade machine. This led to a rise if virtual reality versions being developed for many popular arcade games. SEGA was developing SEGA VR, a virtual reality headset that was supposed to be sold to consumers at home. However, SEGA VR was canceled eventually.

### 2.1.6 Revival in the 2010s

In 2010, Palmer Luckey created the first version of Oculus Rift. Two years later, he launched a Kickstart campaign for Oculus Rift and raised 2.4 million dollars. This can be seen as the first VR headset that reached consumers and a wide range of developers. In 2014 Facebook bought Oculus for 2 billion dollars, which was the start of a rapid boom in virtual reality development. Sony, Google, and Samsung were publishing their own versions of virtual reality, and wide range of virtual reality applications were developed. By the decade's end, HTC, Apple, Amazon, Microsoft, and other smaller companies jumped in to develop their own VR headsets.

### 2.1.7 The 2020s and beyond

There are many VR headsets in the market, but the most significant market share is on Meta* (previously Facebook). Virtual reality is used in various areas, such as gaming, health care, education, manufacturing, and entertainment.

## 2.2 Reading in VR/AR

This section reviews relevant literature on reading in VR/AR, which is the primary focus of our research.

### 2.2.1 Text size and dimensions

The most relevant studies to our topic assess reading preferences and user experience in VR. Dingler et al. [7] made the first study about reading preferences in VR, which is quite similar to ours. In their study, they asked participants to adjust settings like text size and vergence to find their preferred comfort levels. Based on their results, they made the first design recommendations for font size and text panel dimensions in a VR environment. A similar study that compared Oculus Go and Oculus Quest was done by Kojić et al. [17], where participants adjusted text settings to find the most comfortable and the least comfortable settings for reading. Their study did not find any significant differences in users' reading preferences.

Further studies have investigated reading preferences for Japanese writing by Kobayashi et al. [15] and for Chinese writing by Kwok et al. [19]. Kwok et al. determined that line spacing significantly impacts reading speed. However, it is not clear we can generalize their results beyond their own setup.

*According to IDC AR & VR Headsets Market Insights https://www.idc.com/promo/arvr

A study by Vairinhos et al. [36] conducted tests comparing flat, two-dimensional fonts against three-dimensional, embossed fonts in VR environment. Results demonstrated that the simpler, two-dimensional font style allowed users to estimate distances more accurately than the more complex, three-dimensional styles. This outcome suggests that less visually complex fonts can enhance spatial understanding and user comfort in virtual environments, making them more effective for use in VR applications where accurate distance judgment is critical.

### 2.2.2 Text location

Besides the text attributes, another thing to be aware of is the relative position of the text panel, specifically if it is world-fixed or head-fixed. Studies by Chen et al. [5], and Polys et al. [28] show that head-fixed panels improve task performance. However, both of these studies are quite dated, and it is unclear if the findings are relevant to current technology. Chen et al. used V8 HMD with a resolution of 640x480 pixels, and Polys et al. used a grid display. Another thing to consider is that Chen et al. used text without a background panel, which might be more jarring to read in a world-fixed format.

More recent studies show that users prefer world-fixed text. A study by Orlosky et al. [26] investigated text placement optimization with HMDs and traditional smartphones. Their results also show that with HMDs, users have a better understanding of environmental elements than with smartphones. Kobayashi et al. [15] conducted a study exploring how view settings affect readability and reduce fatigue when reading long texts in VR. The study tested settings like font type, color, size, placement mode (world-fixed or head-fixed), and viewing distance using HMDs. Their results show that world-fixed mode was greatly preferred among users. Another study by Mack et al. [23] found that some head-fixed positions increase perceived cognitive demand. They also found that vertical placement of the text impacts cognitive load more than horizontal placement and that placement above the eyes is optimal for normal working height. In a study about panel designs by Gabel et al. [10] shows that panel design has an impact on user experience but not on user performance. Other research on panel design by Wei et al. [37] investigated user preference for panel curvature and found that users generally prefer flat text panels over curved ones.

### 2.2.3 User experience and outcomes

Baceviciute et al. studied learning outcomes and cognitive processes in educational VR setting [1]. Using EEG measures and learning assessments, they compared learning in three different formats: text in an overlay interface, text in a virtual book, and audio. They found out that text had better learning outcomes and a virtual book had better learning outcomes than an overlay interface. EEG data showed that audio had the least cognitive demand and a virtual book had less cognitive demand than a overlay interface.

Gabbard et al. investigated context switching in a controlled AR environment using a text-based visual search task, which showed that both context switching and focal distance switching (changing the focus distance between different objects) negatively impact user performance by reducing task completion rates and accuracy. The study also noted that these activities increase visual fatigue significantly. [9]

Ding and Ho tried to reproduce physical-book-like experience in a smartphone AR/VR environment [6]. They designed an application with purpose to be intuitive and leverage both VR and AR technologies to enhance the reading experience. It allowed users to interact with virtual texts through gestures, essentially recreating the feel of turning pages in a physical book, but through a smartphone equipped with VR glasses. However, the experience was visually fatiguing and needed more development on the physical gestures to feel more immersive. A study by Li et al. [22] investigated an AR and VR reading aid system to promote deep reading among high-schoolers. The Study compared VR and AR and found no significant difference in reading comprehension between the two, but VR had significantly better user preference and practicality.

Sakamoto et al. explored reading comprehension assessment trough the use of pupillometry[29] (measurement of pupil size and reactivity). They did find interesting data, but did not find any relevant relations that would allow them to asses reading comprehension with pupillometry.

### 2.2.4 Interaction

Aside the text parameters, there are also other things to consider in VR reading. One of those is interaction in VR, and many studies have been made in that matter. A study by Dingler et al. [8] investigated different page turning methods: moving the camera, where player navigates from page to page by moving their position in the virtual space; Moving pages linearly, where pages move towards the reader in a linear arrangement, enhancing reading fluency without requiring the reader to move; And moving pages radially, where pages are arranged around the reader in a radial layout, enabling quick navigation between pages by looking around. According to their results, moving pages linearly towards the player was the most comfortable method. However, they do not compare these with a method that would just imitate a book style, where you change the text in the same position or even literally turn the page.

A paper by Lee et al. [20] introduces a VRDoc software and compares three different gaze based interactions in VR: Gaze select-and-snap, Gaze MagGlass, and Gaze scroll. Weir et al. investigated using VR as a way to help visually impaired people read and found that for some visually impaired people VR can be a great assist in reading over a traditional media [38].

McNamara et al. [24] investigated a technique for optimizing the placement of informational labels in virtual environments using eye tracking to determine user attention and improve information accessibility without causing overload. This technique reveals labels for objects within a virtual environment only when users look directly at them. It significantly improved task accuracy (with nearly 95% accuracy) and reduced visual clutter by minimizing the obstruction of the virtual environment.

### 2.2.5 Resolution

A lesser researched aspect in VR reading is the impact of HMD resolution to reading comfort and effectiveness. To the best of our knowledge, the only study that investigates this is by Kilpeäläinen and Häkkinen [14], where the authors show that smaller font sizes are more legible with Varjo VR2-Pro than with HTC Vive or Meta Quest 2.

## 2.3 VR in general

In this section we review some literature that is relevant to our study or otherwise important to note when talking about virtual reality.

### 2.3.1 Immersion

Bowman and McMahan bring up two essential concepts about how a user experiences virtual reality: immersion and presence. They describe immersion as "the objective level of sensory fidelity a VR system provides" and presence as "a user's subjective psychological response to a VR system" [3]. Their research about immersion shows that better immersion improves the task efficiency of visualization tasks. They also found that CAVE systems give better immersion than head-mounted displays. However, their research is relatively old (from 2007), and head-mounted display technology has improved significantly since then; thus, their findings might not be relevant anymore. Bowman and McMahan also suggest that immersive virtual environments can give better spatial understanding compared to a computer screen and that, in this matter, head- mounted displays perform better than CAVE systems [3]. Interrante et al. researched spatial understanding in a virtual environment using a head-mounted display [13] and found that there was slight distance compression in a virtual environment compared to the real world.

### 2.3.2 User experience

There have also been studies on the more subjective matters of virtual reality. Lhemedu et al. suggest that people find virtual reality more enjoyable than conventional computer screens and that users feel more involved in virtual reality than with conventional computer screens [21]. Sitzmann et al. studied how people explore virtual environments and made saliency predictions based on the data [32]. In contrast, Slavova et al. studied learning outcomes and experiences in virtual reality [33] and found that users feel more immersed in virtual reality learning than studying from slides. Still, there wasn't any clear evidence of virtual reality actually giving better study results.

## 2.4 Reading on computer screen

In this section we review some relevant studies about digital reading. This is important to take into account, even when this is for traditional displays and not head mounted displays, because it is beneficial to compare HMD and traditional results with each other.

### 2.4.1 Comparison to reading on paper

There are some studies that compare reading on digital screens to reading on a physical paper. Shibata et al. did a study that compared the accuracy of finding spelling errors on text when reading on a tablet and when reading on paper [30]. They found that participants were more effective at detecting errors when reading on paper compared to the tablet, with a statistically significant 17.2% higher error detection rate on paper. Interaction with the text, such as pointing and sliding fingers or pens along sentences, was more frequent with paper. This behavior is suggested to contribute significantly to the higher proofreading effectiveness observed with paper. Another study by Shibata et al. focused on reading speed when there is a need to go back and forth between pages [31]. They learned that reading speed was consistently higher on physical paper and page turning was significantly easier.

Al-Sulaimi and Shihi did a literature review on reading comprehension between digital and physical [34] and according to the research cited there, digital reading affects readers attention span negatively, reading speed on paper is faster, reading on digital can increase cognitive load and many users prefer reading from physical media.

### 2.4.2 User experience

Banerjee et al. conducted a study on young adults in India, where they investigated user preferences on font size and type, and came to the conclusion that font size 14 and font verdana were the preferred ones. They also describe that font size and typography play an important role in understanding the complexities of visual information. Cardenas et al. conducted a similar study for senior citizens and had similar results [4]

A study by Billones et al. [2] focuses on identifying the optimal distance between a computer screen and a user to minimize eye strain and fatigue. The research utilizes electrooculogram (EOG) signals to monitor eye movements, particularly saccades, and ultrasonic signals to measure the distance between the user and the screen. The findings suggest that a distance of 20-25 inches is ideal, showing the least number of saccades, indicating minimal eye muscle movement and reduced strain.

Reading from a computer screen has been under study for a quite long time already. Mills et al. describe many parameters to consider in digital reading [25] and while we can find some generalized guidelines and suggestions, personalization might be useful in many cases. Pinter et al. [27] developed an application that adjusts text display features (such as color, size, and pattern of the background) based on the user's preferences, which were determined through a questionnaire.

### 2.4.3 Our contribution

Our contribution to this body of knowledge is to study reading comfort from the users perspective. Unlike many of the previous work, we don't study reading compherension or immersion, only how comfortable the experencie is to the user.

# 3 Methods

The primary goal of this experiment is to investigate how different hardware, specifically the Varjo VR-2 Pro and Meta Quest 2 headsets, affects the reading experience in virtual reality (VR). By exploring key aspects of reading performance and comfort, the data gathered will enable us to address three main objectives:

- **Create Adaptive Text Panels for VR:** Virtual reality presents a unique set of challenges and opportunities for text display. Unlike traditional screens, VR allows the user to interact with text in an immersive 3D space. However, creating a comfortable reading experience in VR is not as straightforward. Text readability depends on multiple factors, such as panel dimensions, font size, and the user's distance from the text. Our goal is to collect data that will help design adaptive text panels that optimize readability for different users, environments, and VR headsets.
- **Understand Differences Between Headsets:** The Varjo VR-2 Pro and Meta Quest 2 differ significantly in terms of hardware specifications, such as display resolution, refresh rate, and the type of user interaction. Understanding how these differences impact user comfort and performance is critical, as it will inform recommendations for selecting headsets based on reading-related tasks. This research will help developers and educators make informed choices when integrating VR into professional and educational environments.
- **User Perception and Experience:** The third objective is to understand how users perceive and interact with each headset during reading tasks. Beyond the technical aspects, user comfort, cognitive workload, and overall satisfaction are essential metrics for evaluating the usability of VR reading platforms. Collecting this data enables us to assess how hardware differences influence the user experience and determine if specific headsets are more suited to reading-intensive applications.

To achieve these goals, we employed a series of quantitative methods, including task-based experiments, eye-tracking, and user questionnaires. This methodological approach not only provides insights into user preferences and performance but also facilitates the development of more personalized, user-friendly VR interfaces. By systematically comparing the two headsets, this study seeks to contribute to the broader understanding of human-computer interaction (HCI) in immersive environments, offering practical guidance for optimizing reading in VR.

## 3.1 Hardware Used

We used two different virtual reality (VR) headsets for this study: the Varjo VR-2 Pro and Meta Quest 2. Both headsets vary significantly in their technical specifications, which directly affect the reading experience in VR. A summary of their specifications is provided in Table 3.1.

**Table 3.1:** Comparison of Varjo VR-2 Pro and Meta Quest 2 Specifications

| **Specification** | **Varjo VR-2 Pro** | **Meta Quest 2** |
|---|---|---|
| Display Type | 2x AMOLED + 2x uOLED | Single fast-switch LCD |
| Resolution (per eye) | 1440x1600 (peripheral) + 1920x1080 (focal) | 1832x1920 |
| Refresh Rate | 90 Hz (peripheral), 60 Hz (focal) | 120 Hz |
| Field of View | 87 degrees | 97 degrees |
| Weight | 605g | 503g |
| Interaction Method | Hand-tracking | Oculus Touch controllers |
| Device Type | PC-powered | Standalone |

### 3.1.1 Varjo VR-2 Pro

The Varjo VR-2 Pro is a high-end industrial-grade virtual reality headset, primarily used in professional environments. It features two types of screens per eye: 1440x1600px AMOLED panels for peripheral vision and a 1920x1080px uOLED panel for the focal area. This design ensures a high pixel density in the center of the visual field, offering crisp and clear text rendering, while the peripheral vision remains slightly lower in resolution. The headset supports hand-tracking using integrated infrared cameras, allowing users to interact with virtual objects without physical controllers. Additionally, the Varjo VR-2 Pro includes eye-tracking, which we utilized to gather detailed data on where users were focusing while reading.

### 3.1.2 Meta Quest 2

The Meta Quest 2 (formerly Oculus Quest 2) is a consumer-focused, standalone virtual reality headset. Unlike the Varjo VR-2 Pro, it operates without being tethered to a PC and features a single LCD screen per eye with a resolution of 1832x1920. The Meta Quest 2 is lighter than the Varjo headset, weighing 503g compared to the Varjo's 605g. Users interact with the Meta Quest 2 using Oculus Touch controllers, as the headset did not initially support hand-tracking when the project began.

## 3.2 Software

The software used in the experiment was developed using the Unity game engine (version 2021.3.13f1) and was tailored specifically for each VR headset. The software provided a virtual environment where users could adjust text panel settings (width, height, distance, and font size) to optimize their reading experience.

### 3.2.1 Virtual Environment Overview

The virtual environment consisted of a central text panel where participants read passages of text and two button panels for adjusting text panel parameters (see Figure 3.1). The text panel was displayed against a neutral gray background with black text, and users interacted with the panel by adjusting various parameters to make reading comfortable. The size and distance of the panel and the font size were adjustable through the interaction panels.

### 3.2.2 Interaction Methods

Users interacted with the software through two different methods, depending on the headset being used:

- **Varjo VR-2 Pro: Hand-tracking** – Users interacted with the text panel and buttons using hand-tracking. By using a "pinch gesture," where the index finger touches the thumb, users could increase or decrease text panel dimensions by moving their hands apart or closer together (see Figure 3.2).

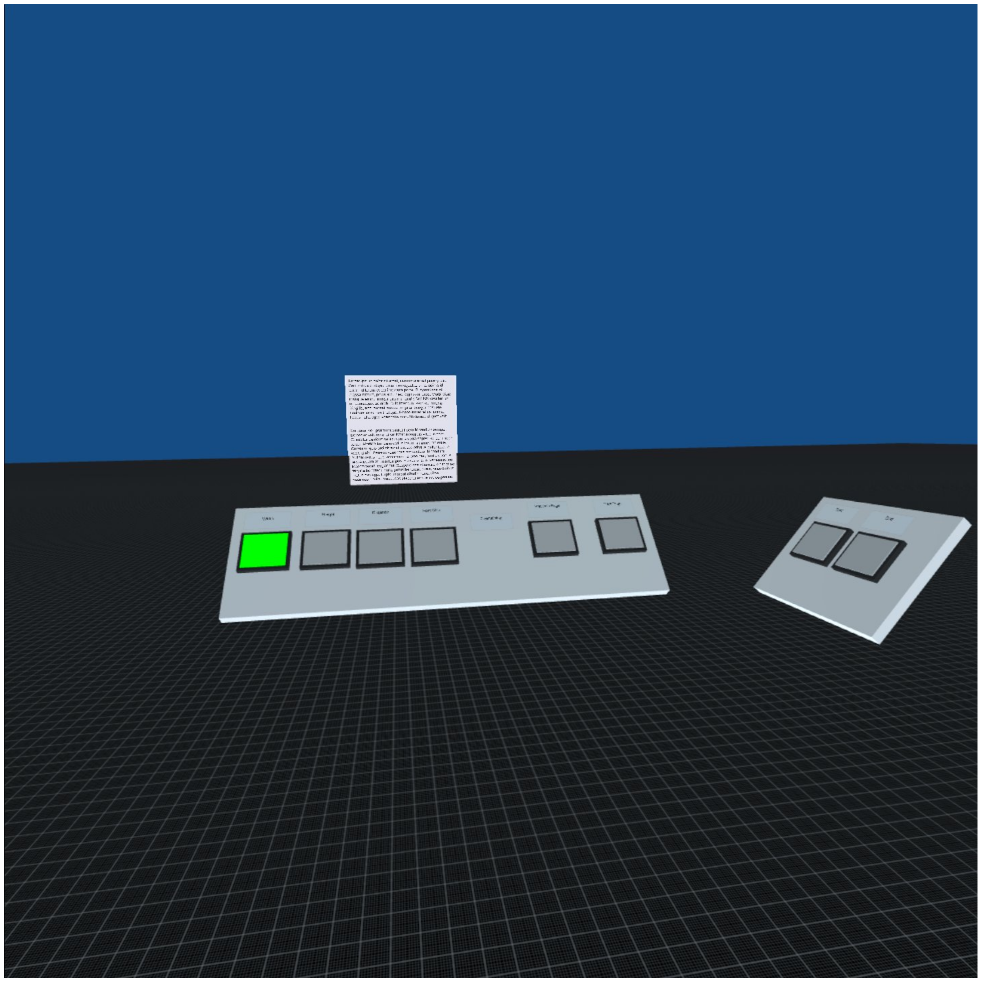

**Figure 3.1:** The virtual environment used for the experiment. The text panel is positioned centrally, while the adjustment buttons are located on either side.

- **Meta Quest 2: Touch Controllers** – Users used the Oculus Touch controllers to adjust the text panel parameters. By holding the index-finger triggers on both controllers, users could move the controllers apart or closer together to modify the text panel size or distance (see Figure 3.3).

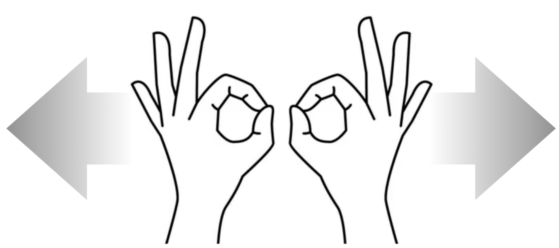

**Figure 3.2:** Hand-tracking interaction for adjusting text panel dimensions with the Varjo VR-2 Pro.

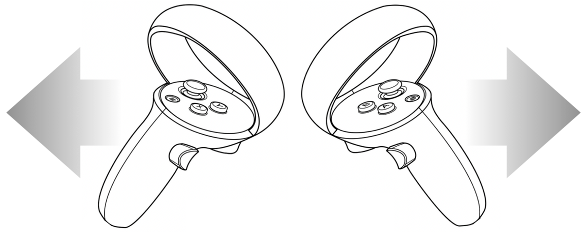

**Figure 3.3:** Controller-based interaction for adjusting text panel dimensions with the Meta Quest 2.

### 3.2.3 Interaction Panel

Users had access to two button panels that allowed them to adjust the text panel dimensions (Figure 3.4). These panels contained six buttons, each corresponding to a different parameter:

- **Width:** Adjusts the width of the text panel.
- **Height:** Adjusts the height of the text panel.
- **Distance:** Adjusts the distance of the text panel from the user.
- **Font Size:** Adjusts the font size of the text on the panel.
- **Next Page:** Moves to the next page (if the text spans multiple pages).
- **Previous Page:** Moves to the previous page (if the text spans multiple pages).

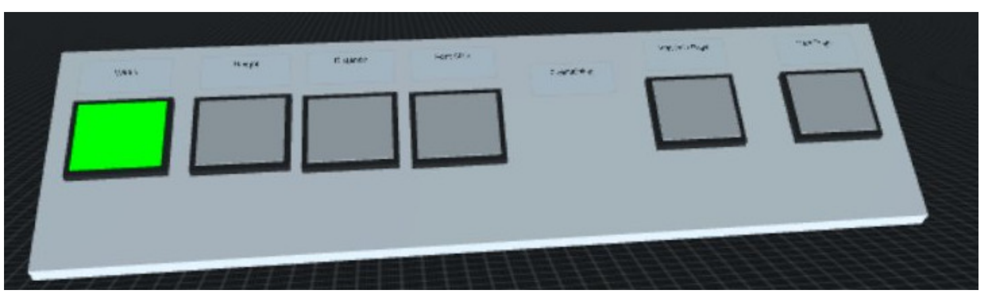

**Figure 3.4:** Button panel for adjusting text panel properties.

## 3.3 Procedure

Participants completed tasks in the virtual environment by adjusting the text panel settings according to comfort and readability. In Task 1, participants were required to adjust three parameters (width, height, distance, or font size) while one parameter remained fixed. This task was repeated 12 times with randomized locked parameters. After each headset iteration, participants filled out the NASA-TLX form to report their perceived cognitive workload.

Task 2 was conducted with only the Varjo VR-2 Pro and involved eye-tracking to monitor participants' reading paths and measure reading speed for fixed text panel parameters. After reading the text, participants pressed the "Next" button to move to the next panel. Eye-tracking data were logged for each trial, allowing us to assess whether users read the text as expected.

## 3.4 Study design

We designed a study with three goals in mind:

- Collect training data for adaptive text panels
- Collect data for verifying results
- Compare Varjo VR2-Pro and Meta Quest 2

### 3.4.1 Tasks

We designed two separate tasks for participants, here referenced by Task one and Task two.

#### Task one, Adjust Text Panel Until Comfortable

In this task, three of the four buttons used to select the parameter to modify are available, and one is disabled. The disabled (meaning uneditable for the user) parameter is set to a random value, and the task is to set the three available parameters so that the text is comfortable to read. The user does this with 12 different setups, where the disabled parameter changes each time.

Users are presented with the following criteria when deciding how to set the panel for comfortable reading:

- It feels comfortable to read the text

- Try to minimize horizontal and vertical head movements
- Try to fit as much text as possible while still being comfortable to read

If they cannot get it to a comfortable setting at all, they are advised to press the "Bad" button, which marks it invalid.

The random values for the disabled parameter have been generated with a Python script (See Appendix A).

The distribution of these generated values can be seen in figure 3.5. The randomness comes when we shuffle the generated values and we select the next unused 12 parameters for each user.

The parameter to randomize is always chosen in this order: height, width, distance, and font size. With 12 per user, each user has a single parameter randomized precisely three times.

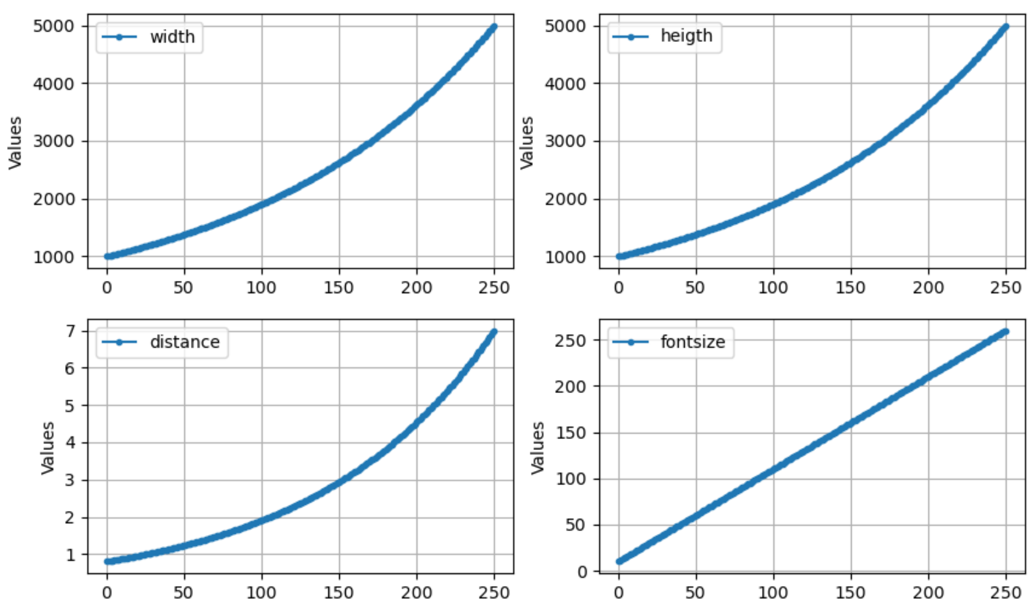


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**Figure 3.5:** Text panel parameter distribution

This task is done twice, once with Varjo and once with Oculus. The order of the headsets is balanced among user, where about half start with Varjo and half with Quest. Both tasks use the same random parameters per user. The only difference is that with Varjo, users use hand-tracking to interact with the task objects, and with Quest, users use controllers.

We save to a file the values of the parameters that the user has chosen.

#### Task two, Reading speed

This task is done with Varjo only because it needs eye-tracking. Before the actual task starts, users have to complete eye-tracking calibration. Users are presented with ten pre-curated semi-random text panel sizes, and their task is to read the text on the panel. After reading all the text, they have to press the "Next" button, after which they get another text with another random panel. This is done until they have read all ten texts.

We do two kinds of data logging here. First, we log the timestamps when the user presses the button so that we can calculate the time it takes to read each text. Second, we use the eye-tracking data to accurately track where the user has been looking on the text panel. From that, we can draw figures of their reading path and use the eye-tracking data to make the reading speed calculation more accurate because we can see when the user started to look at the text panel and when their gaze went elsewhere. We still use the timestamps from the buttons to determine if they had finished reading after their gaze shifted away from the text panel or if they just had a break (like looking elsewhere for a few seconds or closed their eyes) and continued where they left.

### 3.4.2 Questionnaires

Questionnaires are a secondary data collection method in our study. We had two questionnaires and a semi-structured interview. First, there is a pre-questionnaire before the experiment, then NASA-TLX after both iterations of task one, and then the semi-structured interview after task two.

#### Pre-questionnaire

The purpose of this questionnaire is to collect data that might be relevant when looking for correlations in the data. A pre-questionnaire was completed after the instructional video and before the first experiment. In this questionnaire, we ask about the participant's study area, gender, age, if they have eye-glasses, if they have dyslexia, do they have any previous experience with virtual reality, and questions about how often they read for pleasure with traditional books, backlit screens, and non-backlit screens.

We assume that age, gender, and field of study do not correlate meaningfully with the preferred panel transformation. We also believe there will be no correlation between people with and without glasses. There will probably not be enough people with dyslexia to draw any conclusions if dyslexia shows some correlations, but we collect that data in case that people with dyslexia would have very different results compared to people with dyslexia and could then be classified as outliers.

People who like to read for pleasure more than others might prefer different kinds of panels, and there might be an observable correlation between people who read more from books and non-backlit screens and people who read more from backlit screens.

All of the questions are closed-ended with multiple choices, except the first one (current study course; we could not list all possible studies). Two multiple-choice answers had open-ended choices: Gender (prefer to describe) and "Do you own any virtual reality devices? If yes, which ones?"

The multiple-choice answers were decided with some thought. Past experience with virtual reality choices are based on the most common kinds of virtual reality experiences and the question about how often participants read for pleasure has a simple five-step scale (never, rarely, sometimes, often, every day) that is easy to understand. However, exact numbers (for example, once a year, once a month, etc.) could be better choices because different people might have different opinions on what "sometimes" or "rarely" means.

#### NASA-TLX

After each task one (Adjust Text Panel), we give the participant the NASA Task Load Index form. This is for comparing the task load between the two virtual reality headsets. NASA-TLX consists of 6 semantic-differential-scale questions. We do not use the part that would be used to set weights but instead of use weight of one on every question every time.

#### Semi-structured interviews

After all tasks, we asked which virtual reality headset the participant preferred to use, what were the pluses and minuses on each headset and which one was better for reading. We aim to collect data on preferred HMD, what participants liked or disliked on each one, and what are the reasons. We can then try to analyze if some of the reasons are heavily tied to the hardware or if there are problems with our software.

**Ethics**

Participants sign a consent form after being informed of what the study contains. Participants are pseudo-anonymous. All the data and analysis are done for anonymized participant numbers, but because the participant has a right to ask us to delete all their data, we have one connection from their name and email address (needed for the consent form) to their data. All data is stored according to the GDPR.

### 3.4.3 Procedure

The experiment was formed as follows:

1. Show user instructional video
2. Give user consent form
3. Give user first questionnaire
4. User does task Task "Adjust Text Panel" with Varjo or Oculus
5. Give user NASA-TLX form
6. User does task Task "Adjust Text Panel" with Varjo or Oculus (different than in 4)
7. Give user NASA-TLX form
8. User does task Task "Reading speed" with Varjo
9. Ask user which HMD they prefer and what they see their differences are

## 3.5 Summary

We collect data with questionnaires and with eye-tracking in Varjo VR-2 Pro. Participants go trough multiple phases of study in a virtual environment. They have two kinds of tasks: "Adjust Text Panel" and "Reading speed". Afterwards the participant answers question in a semi-structured interview.

# 4 Results

## 4.1 Participants

There were 20 participants (11 male, 5 female, 3 nonbinary, one prefers not to disclose) recruited for the study. Participants were recruited using posters on the local university's campus and sending messages to different mailing lists and instant messaging groups.

Most participants studied or had studied in higher education (19/20), but there was diversity in degree courses (social sciences, computer science, arts, humanities). The participants' median age was 26, with an average of 25.95. Seven wore glasses. The majority of the participants had some previous experience with virtual reality (19/20): games (16/20), movies (9/20), stereoscopical images (8/20), and VR experiments (7/20). However, only some (5/20) reported owning a virtual reality headset, and the majority did not experience VR often: (7/20) never, (8/20) rarely, (3/20) sometimes, (1/20) very often, and (1/20) every day.

Most (16/20) said they read for pleasure at least sometimes: (6/20) sometimes, (6/20) very often, and (4/20) every day, while only (4/20) reported rarely, and none said they never read for pleasure. Most read from digital books and this seems to divide people into two groups: Participants reported reading for pleasure, often on backlit screens or in physical books, but no one reported using both formats often.

## 4.2 Data Analysis Methods

From the investigation into reading preferences, a total of 448 data points were gathered from 19 individuals. Participant 17 was excluded from the analysis because the log file was not properly saved on the Varjo headset. Among the remaining participants, eight data points were missing as these individuals reported being unable to finish the task. The attributes of the text panel showed strong correlations with each other, ranging from 0.582 to 0.810 (Pearson's $r^2$). A multivariate regression model was applied to analyze the data, and $\eta^2$ was used to assess the impact of each independent variable. Upon scrutinizing the data obtained from the NASA-TLX forms, it was observed that most

| Reference | Headset | Preferred Size (dmm) | Preferred Size (pt@1m) |
|---|---|---|---|
| Dingler et al. [7] | Oculus Rift CV1 | $32 \pm 11$ | 132 |
| Kojić et al. [18] | Oculus Go | $16.01 \pm 9.25$ | 66 |
| Kojić et al. [18] | Oculus Quest | $17.87 \pm 24.52$ | 74 |
| This thesis | Meta Quest 2 | $10.98 \pm 6.90$ | 45 |
| This thesis | Varjo VR2 Pro | $8.88 \pm 4.71$ | 37 |

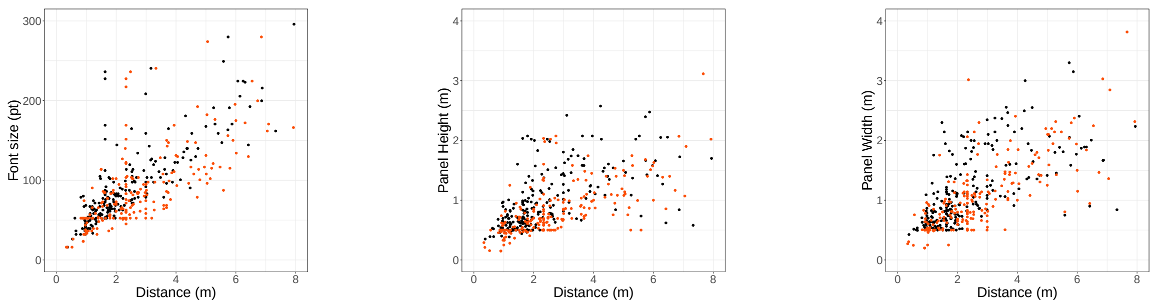
**Table 4.1:** Summary of average preferred font sizes across publications and VR headset models. Average preferred font size is shown in distance-independent millimeters (dmm) as $mean \pm sd$ and the corresponding closest integer point size at a viewing distance of 1m.

subscales exhibited statistical significance as per the Shapiro-Wilk normality test. The non-parametric Wilcoxon signed-rank test was utilized to compare the cognitive workload of each headset, and the point-biserial rank correlation coefficient was employed to gauge the effect size.

As for the study of reading speed, we collected a total of 200 observations from 20 participants. We did correlation analysis and did not find any relevant correlation in reading speed.

## 4.3 Comparison with Previous Guidelines

We compare our results with previously published guidelines for the angular size of text in distance-independent millimeters as seen in table 4.1. The angular size of text is a concept that combines the physical size of the font (how big the letters are) and the distance from which it is viewed to determine how easy it is to read. Distance-independent millimeters (dmm) are used as a measurement. One dmm is equivalent to one mm at a one meter viewing distance. Table 4.1 shows our comparisons to previous work, comparing preferred size in dmm and points at one meter, and we can see that as the resolution of the headset increases, the optimal font size decreases. This suggests that guidelines for displaying text in VR should be re-evaluated based on the display technology of a used device. We informally observed the distance at which a person held a physical book with a font size of 10pt away from their face while reading to be approximately ∼8.0dmm (closely resembling the 8.88dmm measured with the Varjo headset). This implies that for high-




(a) Font Size (b) Panel Height (c) Panel Width

**Figure 4.1:** Raw preference data from Varjo VR2 Pro (red points) and Meta Quest 2 (black points). Height, width, and font size were lower for Varjo VR2 Pro than Meta Quest 2 on average for the same viewing distance.

resolution headsets, we may consider applying comparable guidelines for VR as those used for printed media.

## 4.4 Reading preferences

We utilized a multivariate regression model to analyze reading preferences and capture the collective variance among dependent variables. This approach minimizes the standard errors on model coefficients compared to conducting separate regression analyses, enhancing statistical power. Our study included three dependent variables about the virtual text panel (height, width, and font size) and three independent variables (viewing distance, headset, and participant ID). We applied a log transformation to these variables to address the positive-only nature of height, width, viewing distance, and font size. This transformation also helped reduce the dispersion of data points at larger viewing distances (refer to Figure 4.1 for visual representations of the raw data). The headset variable was treated as a categorical factor to indicate whether the observation was conducted using the Varjo VR2 Pro or the Meta Quest 2.

Table 4.2 presents the results of the multivariate analysis of variance (MANOVA) tests, which determine whether each independent variable (e.g., Viewing Distance, Participant, Headset) should be included in the model, based on the statistical significance of their P-values. Additionally, the table shows the magnitude of the effect each variable has on the dependent variables (height, width, and font size), represented by the effect size (partial $\eta^2$).

| Variable | Test stat. (Pillai trace, V) | P-value | Effect size (partial $\eta^2$) | Confidence interval (95%) |
|---|---|---|---|---|
| Viewing Distance | 0.798 | < 2.2e-16 | 0.80 | [0.77, 0.82] |
| Participant | 0.660 | < 2.2e-16 | 0.22 | [0.07, 0.23] |
| Headset | 0.171 | < 2.2e-16 | 0.17 | [0.11, 0.23] |

**Table 4.2:** MANOVA tests for variable inclusion, effect sizes, and their 95% confidence intervals for reading preference model.

The P-values indicate that all variables—Viewing Distance, Participant, and Headset—are statistically significant ($P < 0.05$), meaning they all have a meaningful effect on reading preferences and should be included in the model. The effect size (partial $\eta^2$) reflects the strength of each variable's influence. For instance, Viewing Distance has a large effect ($\eta^2 = 0.80$), making it the strongest predictor of reading preferences. Participant and Headset also have notable effects, though smaller in magnitude, with $\eta^2$ values of 0.22 and 0.17, respectively.

These results show that variables such as how far away the viewer is virtually, which headset they use, and personal differences significantly affect reading preferences. However, it is important to note that these tests evaluate the significance and magnitude of each explanatory variable's effect, not the predictive accuracy of the overall model.

As shown in Table 4.3, the headset coefficient was negative in all three models, meaning participants chose smaller dimensions (text height, width, and font size) when using the Varjo VR-2 Pro compared to the Meta Quest 2. Specifically, the negative coefficients for the headset variable indicate a reduction in text height by 0.45 units, text width by 0.61 units, and font size by 0.32 units for the Varjo headset, controlling for viewing distance.

Viewing distance, on the other hand, had a positive relationship with text dimensions in all models, meaning participants selected larger text dimensions as the viewing distance increased. This suggests that hardware characteristics like headset type, along with spatial perception (viewing distance), strongly influence reading preferences in virtual reality environments, which addressed RQ1.

**Table 4.3:** Regression Models Predicting Text Height, Width, and Font Size (Participant parameters omitted)

| **Effect** | **Estimate** | **SE** | **95% CI** | | **p** |
|---|---|---|---|---|---|
| | | | **LL** | **UL** | |
| **Text Height** | | | | | |
| Intercept | 1.34 | 0.22 | 0.91 | 1.77 | .004 |
| Headset (Varjo) | -0.45** | 0.15 | -0.74 | -0.16 | .002 |
| Viewing Distance | 0.51** | 0.10 | 0.31 | 0.71 | < .001 |
| **Text Width** | | | | | |
| Intercept | 2.08 | 0.18 | 1.72 | 2.44 | .012 |
| Headset (Varjo) | -0.61** | 0.12 | -0.84 | -0.38 | < .001 |
| Viewing Distance | 0.39** | 0.08 | 0.23 | 0.55 | < .001 |
| **Font Size** | | | | | |
| Intercept | 1.21 | 0.19 | 0.82 | 1.60 | .014 |
| Headset (Varjo) | -0.32** | 0.11 | -0.54 | -0.10 | .003 |
| Viewing Distance | 0.47** | 0.09 | 0.29 | 0.65 | < .001 |

Note: **p < .01, *p < .05. SE = Standard Error; CI = confidence interval; LL = lower limit; UL = upper limit.

## 4.5 Percieved Workload

We also wanted to understand how making adjustments to the virtual text panel differs between the two headsets in terms of perceived workload. This is especially important after seeing the significance of personalization by users' reading preferences.

Table 4.4 shows descriptive statistics and significance tests for the overall task load index and for each subscale of NASA TLX. The perceived workload was 37% higher in the Varjo VR2 Pro compared to the Meta Quest 2 (V=176.0, P=0.008). This was driven by significant increases in mental demand (37%), physical demand (24%), performance (42%), and effort (53%) (see Table 4.4 for results of significance tests). However, we note that the Varjo headset's absolute score (28.17) was considerably lower than the median NASA TLX scores reported for many other tasks, including playing video games and driving a car [11].

| | Meta Quest 2 | | Varjo VR2 Pro | | Test | P-value | Effect | Confidence |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | stat. (V) | | size (r) | interval (95%) |
| Mental demand | 21.50 | 17.18 | 30.50 | 20.25 | 128.0 | 0.015* | -0.67 | [-0.87, -0.28] |
| Physical demand | 20.50 | 17.69 | 25.50 | 20.32 | 113.0 | 0.020* | -0.66 | [-0.88, -0.22] |
| Temporal demand | 15.75 | 15.41 | 19.00 | 19.51 | 55.0 | 0.218 | -0.41 | [-0.77, 0.14] |
| Performance | 17.75 | 17.58 | 25.25 | 17.88 | 111.0 | 0.027* | -0.63 | [-0.86, -0.19] |
| Effort | 27.00 | 21.91 | 41.25 | 20.25 | 111.0 | 0.004** | -0.85 | [-0.94, -0.62] |
| Frustration | 20.75 | 17.27 | 27.50 | 22.45 | 103.5 | 0.069 | -0.52 | [-0.81, -0.02] |
| Overall | 20.54 | 14.31 | 28.17 | 15.41 | 176.0 | 0.008** | -0.68 | [-0.87, -0.29] |

**Table 4.4:** Descriptive and test statistics for NASA TLX ($*$ = statistically significant).

In line with RQ2, the analysis reveals significant differences in perceived workload between the Varjo VR-2 Pro and Meta Quest 2 headsets, with users reporting higher cognitive demand for the Varjo VR-2 Pro despite its superior resolution. As expected in RQ3, physical attributes such as the weight and design of the headsets played a significant role in the reading experience, with participants noting greater discomfort when using the Meta Quest 2 for longer durations.

## 4.6 Semi-structured Interviews

In the semi-structured interviews, we asked participants what they thought of each headset concerning their reading experiences. We broke down their comments into three categories: visual quality, physical comfort, and controls. Some participants referred to the Meta Quest 2 as the "Oculus Quest 2" as the headset has been sold under both names.

- **Visual quality:** Some participants said the Varjo headset had clearer text (4/20, e.g., "*Varjo sharp center is better than Oculus for reading*", P20), but others disliked it because of the visible boundaries between the focal and peripheral displays (5/20, e.g., "*Varjo text in the middle is better, but edges were annoying*" P6). Fewer participants stated that the Meta headset was clearer (2/20, e.g., "[Meta Quest 2 had a] *more clear picture*" P13). Only a single participant mentioned the aliasing issues on the Meta headset ("*Quest ... has more aliasing*" P19); however, other participants may have also noticed it; but lacked the vocabulary to describe what they were seeing.

- **Physical comfort:** Similar numbers of participants stated that the Varjo (3/20) and Meta headsets (2/10) were more comfortable. However, far more participants commented that they preferred the Meta headset because it weighed less (8/10, e.g., "*Oculus: lighter ... Varjo: too heavy*" P10).

- **Controls:** The most common issue participants highlighted was hand-tracking vs physical controls. Half of the participants stated that they preferred the physical controls of the Meta headset's touch controllers (10/20, e.g., "*hand-tracking is okay, but [touch] controllers more accurate and smoother*" P19). A single participant saw the benefit of using hand-tracking while reading (1/20, "[it was a] *plus when no physical controllers*" P1).

## 4.7 Predicting Reading Speed

Our study explored the relationship between virtual reality (VR) display characteristics (height difference, width difference, and fontsize difference) and reading speed through repeated measures correlation analysis. Our goal was to see if we are able to predict reading speed based on display characteristics and the used HMD. However, the study was done only with Varjo HMD, because Meta HMD does not have eye-tracking. Eye-tracking was used to confirm that the user did the experiment as expected. We made graphs that showed the eye-movement path and measured the time user took to read each entry and based on them we manually assessed every entry to see if the results were believable and excluded outliers from our analysis. Table 4.5 shows correlations for height, width and fontsize. Correlations between model predictions and attribute value used were as follows: height ($\rho = 0.108, P = 0.164$), width ($\rho = -0.055, P = 0.475$), font size ($\rho = 0.117, P = 0.132$).

Figure 4.2 shows and example of good eye-track data and figure 4.3 shows an example of an outlier who did the reading too fast and shows off not following the text at all.

With respect to RQ4, correlations, ranging from very weak to weak, coupled with non-significant p-values, suggest that the changes in text panel dimensions and fontsize have minimal to no substantial effect on reading speed. This outcome points to the necessity for further research, possibly with a larger dataset or different methodologies, to explore these relationships more deeply and to understand if other factors not considered in this study might play a more significant role in affecting reading speed in VR environments. Perhaps the amount of text the user needs to read should be much longer to have any

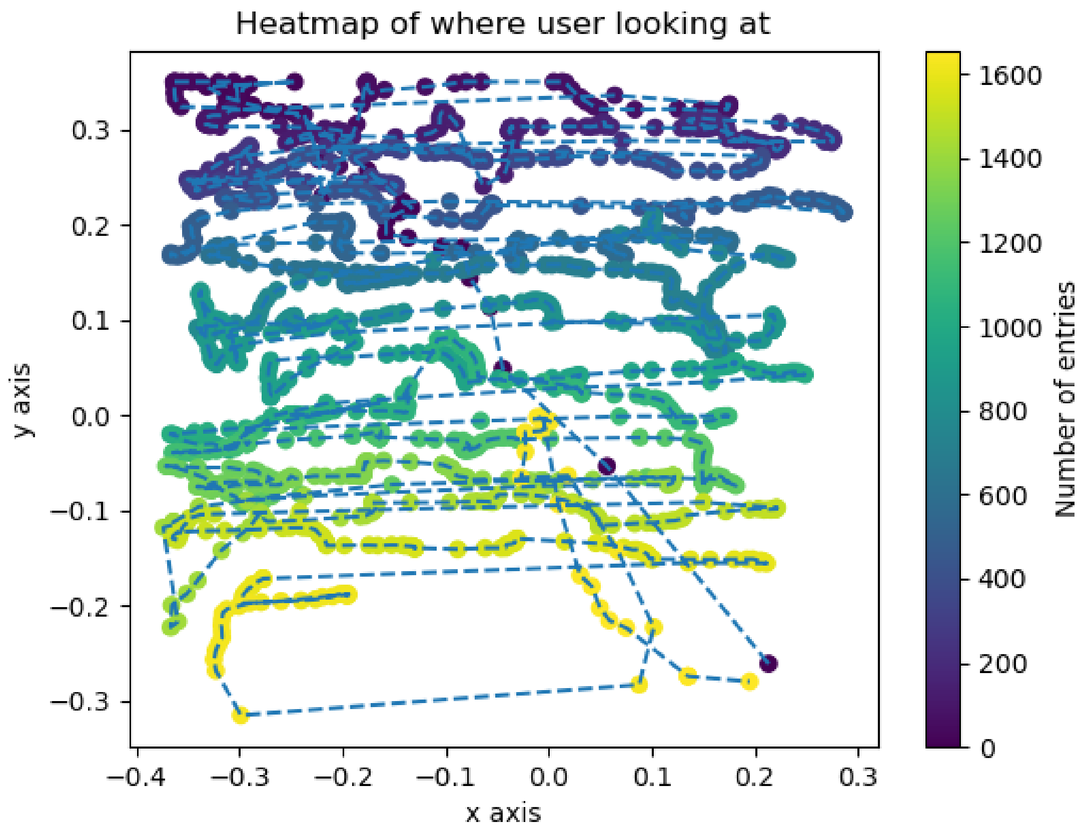



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**Figure 4.2:** Example eye-track data of someone who did read the text

significant results. It is possible that reading comfort does not correlate with reading speed, especially in shorter texts.

**Table 4.5:** Summary of Repeated Measures Correlation Analysis Between Reading Speed and Display Characteristics

| Variable | Correlation Coefficient (r) | p-value | 95% Confidence Interval |
|---|---|---|---|
| Height | 0.15396 | 0.05825 | [-0.00537, 0.30567] |
| Width Difference | -0.14007 | 0.08524 | [-0.29274, 0.01957] |
| Fontsize Difference | 0.06275 | 0.44249 | [-0.09742, 0.21975] |

## 4.8 Recap

This chapter presented the results of our study. The study enlisted 20 participants, a mix of genders and educational backgrounds, primarily from higher education. The recruitment

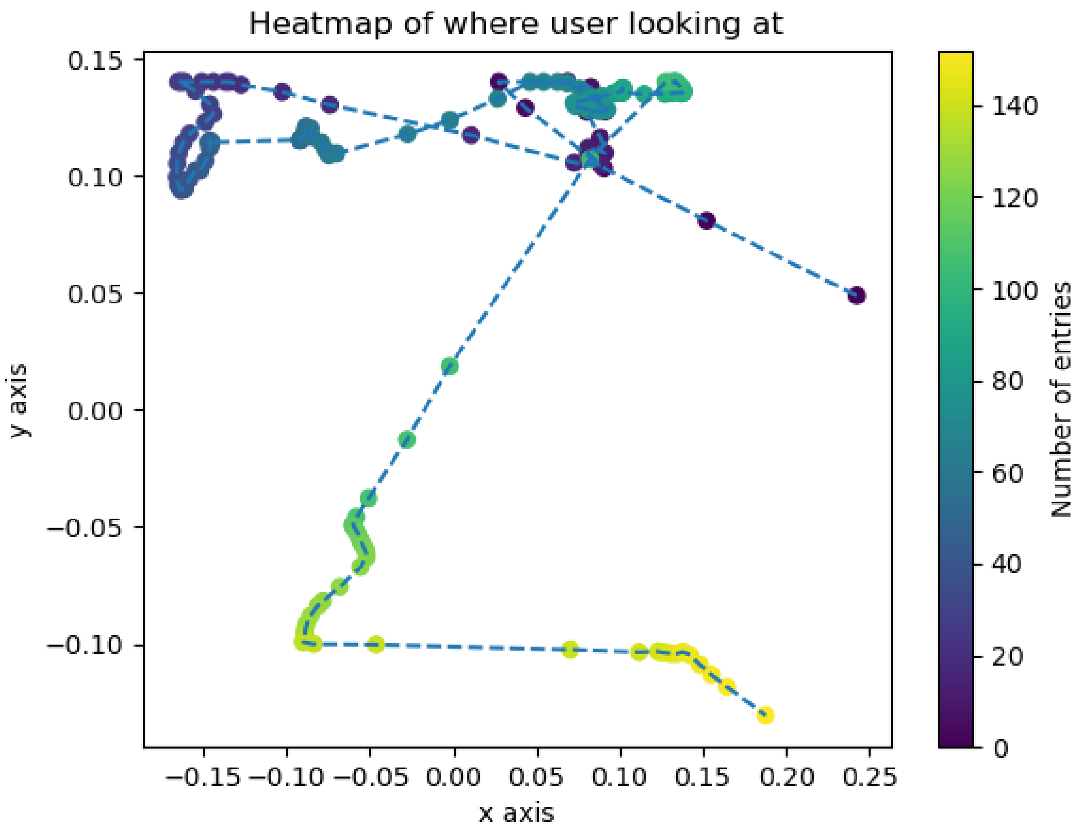


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**Figure 4.3:** Example eye-track data of someone who did not read the text well enough and is an outlier

utilized campus posters, mailing lists, and instant messaging groups. Most participants had prior VR experience, though only a few owned VR headsets. A slight majority of participants had previous VR experience. Despite varied experiences with VR, ownership and frequent usage of VR headsets were relatively low.

Our analysis of reading preferences revealed strong correlations among text panel attributes, emphasizing the influence of individual preferences and the specific VR headset on reading comfort. Notably preferences for font sizes and text panel dimensions differed significantly between the Meta Quest 2 and Varjo VR2 Pro headsets, suggesting a need for personalized settings.

Participants reported clearer text and comfort with the Varjo headset but noted its weight was heavier than the Meta Quest 2. The Meta Quest 2 was favored for its lighter weight and easier-to-use physical controls.

The Varjo VR2 Pro was associated with a higher perceived workload, particularly regarding mental and physical demands. This suggests the importance of considering user comfort and workload in VR reading environments.

The study attempted to correlate VR display characteristics with reading speed but found minimal effects. This highlights the complexity of reading in VR and the potential for further research in this area.

Overall, this study underscores the significant impact of VR headset characteristics, individual preferences, and physical comfort on reading experiences in virtual environments. It suggests a path forward for tailoring VR reading platforms to enhance user engagement and comfort, potentially influencing the development of future VR technologies.

# 5 Discussion

This chapter aims to interpret and discuss the findings presented in the results chapter. It summarizes and discusses the main findings, research questions, and hypotheses. The findings are compared with the literature reviewed in Chapters 2 and 3.

## 5.1 Interpretation of Findings

The findings from the study provide answers to the research questions and support the hypotheses. The Varjo VR-2 Pro and the Meta Quest 2 virtual reality headsets were found to have different impacts on the reading experience in a virtual environment, addressing RQ1, RQ2 and RQ3. The differences in the reading experience between the two headsets were found to be significant, with participants showing distinct preferences for text size and panel dimensions on each device. The width, height, and distance of the text panel and the font size were found to affect the reading experience, which addressed RQ4.

The findings align with previous studies and theoretical expectations, as discussed in Chapters 2 and 3. However, some differences were found. While prior research indicated minimal user preference differences between VR headsets, such as the Oculus Go and Oculus Quest, our study found significant differences between the Varjo VR-2 Pro and Meta Quest 2. This finding contrasts with earlier work by Kojić et al. (2020)[18], who observed minimal variation in user preferences between the Oculus Go and Quest headsets, despite differences in resolution.

This could also be attributed to the higher resolution and different display technologies used in the Varjo VR-2 Pro, which allowed for smaller and more precise font sizes, as noted by Kilpeläinen and Häkkinen (2023)[14]. Users in our study needed the text bigger on Quest 2, likely due to its lower resolution. Similarly, studies by Dingler et al. (2018) [7] showed that display characteristics, such as font size and text panel dimensions, are crucial in determining the optimal settings for reading comfort in VR and our results are in line with that. These findings reinforce the idea that the technological differences between the headsets, specifically in terms of resolution, are key factors influencing reading preferences in VR.

Overall, the study shows the importance of considering both technological specifications and user comfort in the design of VR reading environments. These findings have significant practical implications, offering valuable insights for the development of future VR technologies and applications that aim to optimize the reading experience. However, since according to our study these parameters don't affect reading speed, they don't need to be taken into consideration if one want's to cater for reading speed and not reading comfort.

## 5.2 Explanation of Unexpected Results

The data revealed some unexpected patterns. For example, users reported higher overall reading satisfaction with the Meta Quest 2 despite the Varjo VR-2 Pro's higher resolution. These unexpected findings could be due to several reasons. One possible explanation could be the Varjo VR-2 Pro's weight and ergonomics, which might have caused discomfort over extended use, overshadowing its superior display quality.

The conditions in the study also explain some of the unexpected results. For instance, the study's duration and the environment in which it was conducted could have influenced user feedback. Participants might have experienced fatigue or discomfort that affected their responses. However, we mitigated this by changing which headset was used first with different participants. Additionally, the use of different interaction methods (hand-tracking vs. controllers) might have introduced a variable that impacted user preferences and perceived workload, which is supported by our semi-structured interviews where many people cite that interaction with the Meta Quest was much easier than with the Varjo VR-2 Pro.

## 5.3 Significance

The findings contribute with some significance to the field of VR and reading experiences. They provide new insights into how different VR headsets impact the reading experience in a virtual environment and how text formatting parameters can be optimized for reading in a virtual environment. This adds to the existing body of knowledge by demonstrating the importance of headset design and text presentation in enhancing user experience.

The findings have significant practical implications. They can be applied in real-world settings to improve the reading experience in VR. For practitioners in VR, education, or other relevant fields, the findings mean that careful consideration must be given to the choice of VR headset and the configuration of text display settings to ensure user comfort and efficiency.

## 5.4 Limitations

The study has several limitations. These include methodological constraints, challenges in data collection, and limitations in the scope of the research. For example, the age range of participants was relatively young and not fully representative of the general population, which might affect the generalizability of the findings. Additionally, using the default control method for each headset (hand-tracking with Varjo, controllers with Meta) may have overshadowed other equally valid critiques that were otherwise missed.

These limitations might affect the results' interpretation or the findings' generalizability. For instance, the study's reliance on self-reported data might introduce bias, and the short duration of reading tasks might not capture the long-term effects of VR reading on user comfort and performance.

## 5.5 Future Research

Future research could overcome some of this study's limitations by including a larger and more diverse sample of participants and extending the duration of the study to observe long-term effects.

Based on the findings, new areas of research have opened up. Future studies could explore the impact of different interaction methods on reading in VR, the effects of prolonged use on user comfort and performance, and the potential benefits of personalized text settings. Specific questions or hypotheses for future studies could include the optimal balance between display quality and ergonomics for different user demographics and the development of adaptive VR systems that adjust text settings in real-time based on user feedback.

## 5.6 Conclusion

In conclusion, this chapter discusses the main findings from the results chapter, explains unexpected results, highlights the significance of the findings, acknowledges the study's limitations, and proposes directions for future research.

Final thoughts on the research process and findings are that the study provides valuable insights into the complexities of reading in VR environments. The results emphasize the need for continued exploration into the interplay between technology and user experience, ensuring that VR applications are practical and comfortable for diverse users.

# 6 Conclusions

The purpose of this chapter is to provide a comprehensive summary of the findings and insights gained from this research. This study aimed to investigate the reading experience in virtual reality by comparing the use of two different VR headsets, the Varjo VR-2 Pro and the Meta Quest 2, and examining their impact on user preferences.

## 6.1 Recap

This research was driven by the need to understand how different VR headsets affect the reading experience in a virtual environment and how we can optimize text in virtual environments to ensure a comfortable and overall pleasant reading experience. The research questions focused on the differences in reading experience between the Varjo VR-2 Pro and the Meta Quest 2 virtual reality headsets, and how the text's width, height, distance, and font size affect the reading experience.

## 6.2 Synopsis of Key Findings

This study provides valuable insights into the factors that influence the reading experience in virtual reality. The key findings are as follows:

1. **Significant Differences Between Headsets**: The Varjo VR-2 Pro and Meta Quest 2 headsets offer notably different reading experiences, with the Varjo VR-2 Pro consistently rated as more comfortable for reading due to its higher resolution and more precise text rendering capabilities. However, Varjo VR-2 Pro had also greater perceived physical- and mental workload and Quest 2 was favored for its lighter weight and easier-to-use physical controls.

2. **User Preferences for Smaller Text on Varjo VR-2 Pro**: Participants preferred smaller font sizes on the Varjo VR-2 Pro compared to the Meta Quest 2, likely due to the Varjo's higher resolution, which allowed for clearer and more legible text.

3. **Minimal Impact of Text Panel Dimensions on Reading Speed**: Although changes in text panel attributes (height, width, font size) influenced reading preferences and comfort, their effect on reading speed was minimal. Weak correlations were found between text panel dimensions and reading speed, suggesting that other factors, such as task complexity or user familiarity with VR, may play a larger role.

4. **Increased Workload on Varjo VR-2 Pro**: Despite the Varjo VR-2 Pro's superior display quality, participants reported a higher perceived workload when using the Varjo compared to the Meta Quest 2, likely due to the precision required in adjusting the text to optimal readability settings.

These findings highlight how both hardware and display characteristics influence the VR reading experience, with the Varjo VR-2 Pro offering a more refined experience at the cost of increased mental and physical demand.

## 6.3 Final takeaway and concluding thoughts

The research contributes to the existing body of knowledge by providing empirical evidence on how different specifications in the Varjo VR-2 Pro and Meta Quest 2 affect the reading experience. The findings of this study will inform educators, designers, and developers on how to design easily readable text content in virtual reality environments. Future research could further explore the impact of other factors on the reading experience in virtual reality. This study serves as a stepping stone for future investigations into the optimization of text presentation in virtual reality.

In conclusion, this research has shed light on the reading experience in virtual reality, providing valuable insights for both academia and industry. The journey of exploring the virtual reality reading experience has been challenging yet rewarding, and it is hoped that this research will inspire further exploration in this fascinating field.

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# Appendix A Python Code

Python code for generating possible panel values.

```python

from matplotlib import pyplot as plt
import random

hrange = [1000, 5000]
wrange = [1000, 5000]
drange = [0.8, 7]


steps = [element * (1/250) for element in range(0,251)]

hlist = [((hrange[1]**element)*(hrange[0]**(1-element))) for element in steps]
wlist = [((wrange[1]**element)*(wrange[0]**(1-element))) for element in steps]
dlist = [((drange[1]**element)*(drange[0]**(1-element))) for element in steps]
flist = list(range (10, 261)) #linear

random.shuffle(hlist)
random.shuffle(wlist)
random.shuffle(dlist)
random.shuffle(flist)

f = open("modeslist.txt", "a")

for i in steps:
    f.write("h " + str(hlist.pop(0)) + '\n')
    f.write("w " + str(wlist.pop(0)) + '\n')
    f.write("d " + str(dlist.pop(0)) + '\n')
    f.write("f " + str(flist.pop(0)) + '\n')
f.close()
```