Exploring the Impact of Display Field-of-view and Display Type on Text Readability and Visual Text Search on Large Displays in Virtual Reality

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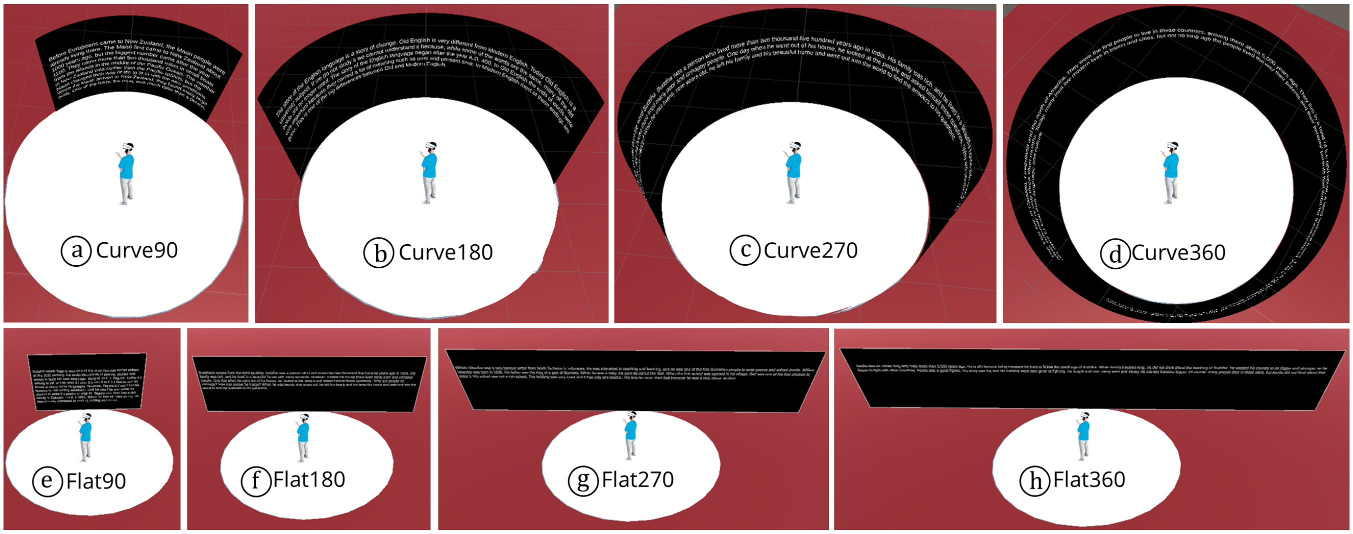

Figure 1: (a-d) four different curved display field-of-views for a 2000R display and (e-h) corresponding flat display layouts with equivalent width. Here, numbers such as 360 and 90 refer to the viewing angle of the display.

ABSTRACT

Large curved displays enhance the viewing experience beyond flat screens by more closely aligning with the human field of vision. Despite the growing prevalence of curved displays in immersive environments, there remains a significant gap in understanding how different display field-of-views (i.e., semicircular, fully circular) influence user experience, particularly regarding reading comprehension and visual search performance in VR. This study examines text readability and visual text search across four curved layouts (90°, 180°, 270°, 360°) and their flat counterparts. Findings indicate that narrower field-of-views significantly improve reading speed over wider ones, and curved displays outperform flat ones in search accuracy. Curve90 (90°) was preferred for its lower subjective workload. Participants preferred the Curve90 display due to its ergonomic advantages and lower perceived effort, while flat displays with wider field-of-views were found to be more demanding. These results offer guidelines for optimizing reading and search tasks in virtual displays.

KEYWORDS

Display Field-of-view, Large Display, Text Readability, Visual Search

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1 INTRODUCTION

Large displays, integral to diverse applications ranging from data visualization [4, 7, 14, 20] to collaboration [11, 48, 58] to entertainment [5, 31, 59], primarily come in two configurations: Flat and Curved. Although prior work [4, 5, 28, 35, 40, 47] primarily focused on flat screens, curved displays offer a distinct advantage by providing a more immersive experience that aligns with the natural human field of view, situating the content uniformly around the

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users [36, 60]. This immersive experience has been shown to increase task performance and satisfaction in users, demonstrating the potential benefits of curved displays over their flat counterparts [17, 38, 50]. However, it is difficult to develop and use large curved screens due to hardware and space requirements [10, 15, 65, 66]. Prior studies [39, 67] have indicated that virtual curved displays can perform similarly to physical ones, suggesting that VR environments offer a viable platform for exploring the unique features of curved displays without the constraints of space and cost [13, 65–67]. Thus, VR presents an opportunity to explore the use of flat and curved displays in virtual reality simulations across diverse settings, including classrooms, libraries, training simulators, meetings, and conferences. Despite the recognized benefits [1, 16, 18, 36, 44, 45, 60, 68, 70] of large curved displays, there has been relatively little attention given to the exploration of large curved virtual displays in research. This gap in research highlights an opportunity for further investigation into the potential of large curved virtual displays, particularly the effect of display field-of-view.

Prior research [6, 38] highlights the positive effects of specific curvatures, such as 2000R on usability and visual fatigue. Researchers also found the ideal viewing distance to be equal to the display's curvature radius [50, 51] for reading and viewing tasks. While there is some evidence from existing work that display field-of-view affects task performance, these findings are inconclusive. For instance, Liu et al. [41, 42] compared semicircular and flat displays for graph comparison and spatial memory tasks; however, they did not find any significant difference in task performance between the two display layouts. Changing the field-of-view of a display can alter paragraph width, which has been found to impact reading accuracy, with narrower paragraphs leading to faster reading times and better comprehension [9]. This motivates exploring display field-of-view in a more granular way such as quarter circular, three-fourth circular, and fully wrap-around display field-of-views. To the best of our knowledge, no existing studies investigated display field-of-view in areas critical to user experience such as text readability and visual search. As a result, there exists a research gap providing a clear guideline to the VR developers for how the field-of-view of flat and curved displays particularly for text readability and visual text search.

This work aims to address these limitations by focusing on how different curved display field-of-view affect user performance. As virtual reality becomes more pervasive, understanding the interplay between display field-of-view and user experience is crucial. In this paper, we explore the effect of *display field-of-view* and *display types* on text readability and visual text search performance within a VR environment. We consider two *display types*: Flat and Curved. We have defined four curved *display field-of-views*: Curve90 (quarter circle with a 90-degree viewing angle), Curve180 (semicircle with a 180-degree viewing angle), Curve270 (three-fourths circle with a 270-degree viewing angle), and Curve360 (full circle with a 360-degree viewing angle). We have implemented flat displays with equal widths corresponding to each curved field-of-view. For example, the width of Flat90 matches that of Curve90. We term a combination of curved and flat displays with the same width as a *display field-of-view pair*. In total, we have four display field-of-view pairs: Curve90 and Flat90; Curve180 and Flat 180; Curve270 and Flat270; Curve360 and Flat360.

We ran a user study where participants performed text reading and visual text search tasks on all of these displays. Our key findings reveal that *display field-of-view* significantly affected reading time for the text reading task. More specifically, participants were faster in the text reading task with the *display field-of-view pair* 90, 180, and 270 compared to the *display field-of-view pair* 360. For the visual text search task, we discovered that the *display type* significantly influences search accuracy, with curved displays outperforming flat displays.

The contributions of our paper are:

- Exploring the impacts of various *display types* and *display field-of-views* in VR
- Providing empirical evidence on how different display configurations affect text reading and visual text search, two critical aspects of user interaction
- Offering design guidelines for text readability and visual text search in VR

2 RELATED WORK

In this section, we review the closely related prior works that inspired us throughout our exploration and investigated different dimensions of text readability and visual search in different domains.

2.1 The effects of display curvature and display field-of-view

The debate between flat and curved displays has been a topic of interest in the research community. Research has demonstrated that curved screens, due to their enhanced ergonomics, are more suitable for visual tasks compared to flat displays [1, 18, 36, 60, 68, 69]. Display curvature determines how curved a display is. The curvature of curved displays is denoted by radius in millimeters followed by the letter "R" [36]. For instance, Shupp et al. [60] conducted a study comparing the performance of users on a large flat display and a 762R (display radius 30") curved display while engaging in various geospatial tasks. Their findings revealed that curved displays demonstrated several advantages over flat displays: i) higher performance and ii) reduced region bias effects (related to the position of elements on the display) for both search tasks (such as finding an icon on a map) and comparison tasks (such as comparing values from static visual data). Zannoli and Banks [70] found that a major advantage of curved screens minimize the distortion of the image surface near the screen's boundaries. For this reason, they found that curved screens can accommodate a wider range of user positions compared to flat screens. Wei et al. [69] examined the impact of different 3D surface shapes on the reading experience in virtual reality (VR) through two user studies. The results showed that the horizontal cylinder surface was more comfortable to read on than the sphere surface. Therefore, most research on curved displays focus primarily on horizontally curved displays. Although display curvature [1, 17, 36, 50] is well explored in previous studies, until recently there was no work on the effects of display layout [41, 42]. A recent study by Liu et al. [41] ran user studies to compare three different layouts: flat, semicircular, and fully circular for data visualization in a VR environment based on chart comparison and finding max value tasks. However, they did not find any difference in performance between the semicircular layout and the flat layout. Liu et al. [42] further conducted a pattern recall task where participants had to select 5 out of 36 cards arranged in a flat, semicircular display and fully circular layout. Again they did not find any difference in performance between the semicircular layout and the flat layout.

Overall, previous research has indicated that curved displays offer various advantages over flat displays. However, these studies did not specifically examine the influence of curved display properties (such as display field-of-views having different viewing angles) on text readability and visual search.

2.2 Text readability in VR

There is limited research on text readability in virtual reality environments as most research focuses on pointing at targets [19, 53, 61, 66]. Rau et al. [55, 56] compared VR HMDs and desktop LCD screens and found that the reading time was significantly longer (around 10%) for reading text in VR. Similarly, Grout et al. [27] compared VR HMDs and traditional desktop displays for reading tasks in VR. Their results indicated that reading tasks can be performed with near-equivalent performance in the virtual environment compared to traditional displays; however, participants generally preferred reading on-screen to physical paper-based media. Consequently, to improve text readability in VR, researchers examined key variables in UI design that improve the text reading experience in virtual reality (VR). In another work, Kojic et al. [34] asked participants to select optimal values of text size, distance, and color contrast for reading texts with 3 different lengths (i.e., short, medium, and long). Their findings revealed significant differences in ideal reading factor values depending on the text length. Researchers [12] also investigated the influence of rotation on legibility in VR and found that text rotated 60° or more requires a significantly longer time to read and requires a higher font size to be legible. Furthermore, although researchers mention different use cases [25, 32] for longer texts (e.g., 100 words) in VR, most previous work text readability in virtual reality focused on shorter texts [12].

Previous studies have explored different factors text size, user distance, and color contrast. However, the impact of display field-of-view on text readability has not been explored before in virtual or physical reality .

2.3 Visual Search

Visual search is considered one of the most important tasks in VR [49]. Letter search tasks [21, 64] are widely used in experimental psychology to evaluate search performance on computerized displays as simple stimuli such as letters allow to systematically analyze visual search in a controlled environment. However, search performance in VR is different from reading on a 2D monitor. For example, one particular study [24] found faster and more accurate visual search performance in a VR environment than in a 2D condition. Kyung and Park [36] conducted a study comparing 33" and 50" physical displays with different display curvatures (400R, 600R, 1200R, and flat) from a fixed distance of 50 cm. They asked the participants to perform a visual search task [30] for the target letter "A" from a sample pseudo-text. They found that the increased size from 33" to 55" adversely affected the performance of the flat display. However, this adverse effect of increased display size on performance was not seen for curved display configurations, indicating curved configurations should be considered for larger displays. Similarly, Shupp et al. [60] also found that searching for an icon on a curved display was faster than searching for it on a flat display. Lim et al. [38] further explored the effects of curved computer displays on visual icon search tasks. They used six 34-inch 21:9 TFT-LCDs with varying curvatures (flat, 4500R, 3800R, 3000R, 2500R, and 2000R) to evaluate visual performance and fatigue. They found that the more curved displays such as 2000R and 2500R required significantly more time for visual search compared to flatter displays such as 3800R, 4500R, and Flat. Conversely, they found searching on the 2000R display leads to a significantly lower average pupil size compared to searching on the flat display indicating lower visual fatigue for the curved displays such as 2000R.

Overall, although we see some prior work investigating visual search for physical displays, visual search tasks are large unexplored in the virtual reality spaces. Furthermore, although we see display curvature affects visual search performance, the impact of display field-of-view on visual search performance has not been explored in prior research.

2.4 Summary and Goals

Previous research has extensively investigated task performance focusing on display curvature [36, 37, 37, 50], but there is limited knowledge about the effect of task performance on curved displays with varying field-of-views. However, studying the varying physical properties of large curved displays poses practical challenges, including cost and equipment requirements [15]. Liu et al. [41, 42] have highlighted the effect of display field-of-view on spatial memory. However, this effect of display field-of-view needs to be further explored, especially for crucial interaction tasks such as text readability [12, 22, 33, 34, 55, 56] and visual text search [21, 36, 64] particularly on long texts [25, 32]. The use of virtual environments to display 2D content, such as for visual analytics tasks [13], presents new opportunities. Consequently, we explore the effects of display field-of-view and display type users for text readability and visual search on large curved and flat displays provided by virtual reality using HMDs.

Our study has two main goals:

- To establish which display field-of-view and display type ensures higher reading performance (speed and accuracy) for text readability tasks
- To establish which display field-of-view and display type ensures higher search performance (speed and accuracy) for visual search tasks

3 USER STUDY

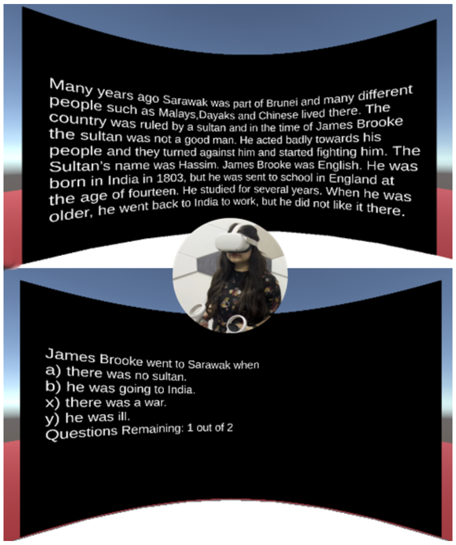
We aimed to understand how different *display field-of-view* and *display types* (flat or curved) influenced text reading and visual text search performance. Therefore, in the first part of the study, we assessed how participants performed text reading tasks on displays with different characteristics. In the second part of the study, the participants performed a visual text search across various *display field-of-views* for both curved and flat displays.

3.1 Display Type and Display Field-of-view

In our study, we considered two *display types*: Flat and Curved. We conducted experiments on four curved *display field-of-views* and four flat *display field-of-views*. The curved displays had a fixed display curvature of 2000R, as it was found to be the most effective in prior work [37, 50–52]. The four curved *display field-of-views* are as follows: "Curve90" is 3.14m wide, "Curve180" is 6.28m wide, "Curve270" is 9.42m wide, and "Curve360" is 12.56m wide. For our curved display, the display radius is 2m, and θ is the viewing angle of the curved display in radians. The formula to find display width is s=rθ. For instance, for the *display field-of-view pair* 90, $s = 2 \times 90\frac{\pi}{180} = 3.14$m. For direct comparison, we introduced four flat displays, each corresponding to the width of its curved counterpart: "Flat90" (3.14m wide), "Flat180" (6.28m wide), "Flat270" (9.42m wide), and "Flat360" (12.56m wide). The height for all displays was set to 2 meters.

3.2 Tasks

3.2.1 Text Readability. Previous research [57] suggested using text that is comparable in complexity to isolate the effects of particular factors, such as *display type* and *display field-of-view pair* in our study. Hence, we used the comprehension passages from a corpus of a standardized English reading assessment [54] to ensure a consistent measure of reading speed. We used 20 paragraphs ranging in length from 100 to 110 words (see Figure 2 top) following the use case of long texts in VR [25, 32]. For each passage, participants were required to answer two questions (see Figure 2 bottom). We maintained a fixed interaction distance of 2 meters from the screen.

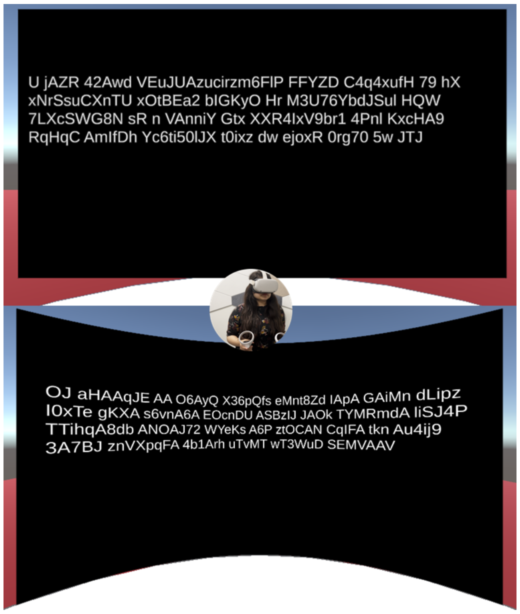


Many years ago Sarawak was part of Brunei and many different people such as Malays,Dayaks and Chinese lived there. The country was ruled by a sultan and in the time of James Brooke the sultan was not a good man. He acted badly towards his people and they turned against him and started fighting him. The Sultan's name was Hassim. James Brooke was English. He was born in India in 1803, but he was sent to school in England at the age of fourteen. He studied for several years. When he was older, he went back to India to work, but he did not like it there.

James Brooke went to Sarawak when
a) there was no sultan.
b) he was going to India.
x) there was a war.
y) he was ill.
Questions Remaining: 1 out of 2

Figure 2: Reading comprehension task on the Curve90 display. Here the top display shows the reading comprehension and the bottom display shows the multiple choice question based on the reading comprehension passage.

3.2.2 Visual Text Search. For the visual text search task, we asked the participants to count the occurrences of "A" in the pseudo-text displayed on different field-of-views and display types. The participants performed a visual search task following the ISO standard (2008b) [29]. Each pseudo-text consisted of 200 alphanumeric characters, including both capital and lowercase letters as well as spaces (see Figure 3). The target letter was capital "A" which the participants had to count from the pseudo-text. The participants had to stand 2m away from each display and count the number of capital "A" for two pseudo text frequency conditions: high frequency and low frequency. We have randomly generated the pseudo-text to ensure that "A" comprises only 13-17 percent for the high-frequency text (see Figure 3 bottom: curved display) and 1-5 percent for the low-frequency text (see Figure 3 top: flat display).



U jAZR 42Awd VEuJUAzucirzm6FlP FFYZD C4q4xufH 79 hX
xNrSsuCXnTU xOtBEa2 bIGKyO Hr M3U76YbdJSul HQW
7LXcSWG8N sR n VAnniY Gtx XXR4IxV9br1 4Pnl KxcHA9
RqHqC AmIfDh Yc6ti50lJX t0ixz dw ejoxR 0rg70 5w JTJ

OJ aHAAqJE AA O6AyQ X36pQfs eMnt8Zd IApA GAiMn dLipz
I0xTe gKXA s6vnA6A EOcnDU ASBzIJ JAOk TYMRmdA liSJ4P
TTihqA8db ANOAJ72 WYeKs A6P ztOCAN CqIFA tkn Au4ij9
3A7BJ znVXpqFA 4b1Arh uTvMT wT3WuD SEMVAAV

Figure 3: Pseudo-text for task 2 visual search task. Here the top display Flat90 shows the low-frequency task with 4% "A" and bottom display Curve90 shows the high-frequency task with 16% "A".

3.3 Font, Size, Length, Background, and Color of the Text

Dingler et al. [22] provide a guideline for text parameters such as text font, text size, text, and background color for user interfaces for virtual reality environments. The two most popular fonts are Times New Roman and Arial [2, 8, 22, 23, 57, 62]. Dingler et al. [22] found 77.8% of their participants preferred the Arial text compared to Times New Roman. Consequently, researchers [12, 33, 34, 62] have widely used Arial for UI in VR. Dingler et al. [22] found 72.2% of users preferred white text on black background compared to black text on a white background. Furthermore, researchers [12, 22, 34, 62] advised to use Google's unit of angular size—dmm: distance-independent millimeter— where the text size is equal to the height of lowercase character "x" at a viewing distance of 1 meter.

To ensure legibility across all display field-of-views we followed the guidelines from previous work, we used the font Arial, set the text size to 50dmm, and presented the text with a contrast of white text on a black background.

3.4 Participants

We recruited 16 participants (8 male, 8 female) aged between 20 and 34 years (avg. 26.18, SD 4.58) from a local university using on-campus flyers. The participants had an average of 1.81 years (SD 1.44) of prior experience using head-mounted virtual reality headsets, such as the Oculus Quest. All of the participants had normal or corrected-to-normal vision. Only two participants had no prior experience using VR. Each participant received $15 as compensation for participating in the study.

3.5 Apparatus

We developed the application using Unity [63]. For the head-mounted display, we used the Oculus Quest 2 [43] (see Figure 2), which has a horizontal field-of-view of 90 degrees. We used the Firebase Realtime Database [26] to log data during the study. We built and tested the Unity application on a workstation equipped with an Intel i9-9900 CPU, 32 GB of RAM, and an NVIDIA GeForce RTX 2080 graphics card.

3.6 Design and Procedure

This experiment employed a 2 (Tasks: Text Readability, Visual Search) × 2 (Display Type: Flat, Curved) × 4 (Display Field-of-view: 90°, 180°, 270°, 360°) × 2 (Questions) within-subjects design. The independent variables were *display type* and *display field-of-view*. The presentation order of the displays was counterbalanced based on *display type* and *display field-of-view pair* using the Latin Square design to reduce the learning effect. Each session was approximately 90 minutes from start to finish and was conducted as follows.

Introduction. (5 min). Participants were given a brief introduction to the study, followed by a demographics questionnaire.

Text Readability. (40 min). The participants were placed 2m away from the screen and were asked to press the trigger of the right controller when ready to start the reading comprehension task. Participants were instructed to read a passage from the virtual display. After pressing the trigger button on the right controller, the passage disappeared, and the questions appeared. Participants could not revisit the passage once the questions appeared. They answered the questions by pressing the A, B, X, or Y buttons on the Quest 2 controller. Each participant read one passage for each unique display configuration (*display type* and *display field-of-view pair*) from a non-repeating random list of 20 passages. Each passage had 2 multiple-choice questions which 4 choices for each question.

Break. (5 min). Participants were given a 5-minute break.

Visual Search. (40 min). The participants had to perform one high-frequency counting task and one low-frequency counting task, identifying occurrences of "A" in the pseudo-text for each of the eight displays. The order of the frequency conditions was randomized. After completing the counting task, the participants had to choose the correct frequency from a multiple-choice question with 4 choices similar to the previous task.

3.7 Measurement

We recorded the completion time and accuracy for each trial. We define reading time as the duration from when participants start reading the passage (indicated by pressing the right trigger) to when they finish (signaled by pressing the right trigger again to proceed to the multiple-choice questions). Similarly, we define search time as the time to finish counting the letter "A" from the pseudo text. We do not record the time to answer the multiple-choice questions. Accuracy is measured by dividing the number of correct answers by the total number of questions asked. We used the NASA-TLX [3] questionnaire to collect participants' perceived workload and their preference for each display.

4 RESULTS

We analyze completion time (reading time and search time) and accuracy with repeated measures ANOVA, and pairwise comparisons with Bonferroni corrections. In case of sphericity violation, we report Greenhouse-Geisser corrected p-values and degrees of freedom. The summary of the results is shown in table 1

Table 1: ANOVA main effects and interaction effects for text readability and visual text search

Criteria	Factor(s)	Text Readability		Visual Search	
		Sig?	ANOVA results	Sig?	ANOVA results
Time	Type		$F_{1,15} = 0.41, p = 0.53$		$F_{1,15} = 0.41, p = 0.53$
	Field-of-view	*	$F_{3,45} = 9.26, p < 0.001, \eta^2$=0.38		$F_{3,45} = 0.64, p = 0.60$
	Type × Field-of-view	*	$F_{3,45} = 6.51, p < 0.001, \eta^2 = 0.30$	*	$F_{3,45} = 2.89, p < 0.05, \eta^2 = 0.16$
Accuracy	Type		$F_{1,15} = 0.01, p = 0.92$	*	$F_{1,15} = 4.42, p < 0.05, \eta^2$=0.02
	Field-of-view		$F_{3,45} = 0.74, p = 0.54$		$F_{3,45} = 0.41, p = 0.74$
	Type × Field-of-view		$F_{3,45} = 0.77, p = 0.52$		$F_{3,45} = 2.26, p = 0.08$

4.1 Text Readability Results

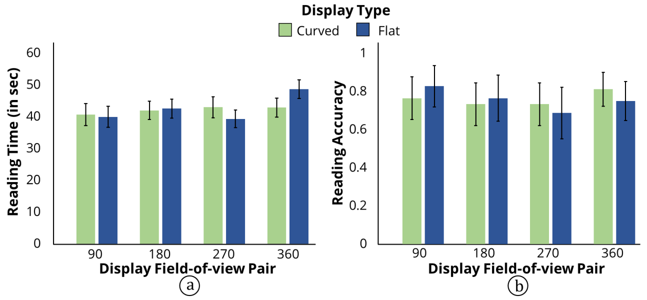


Figure 4: (a) Reading time by *display field-of-view pair* for each *display type* (b) Reading accuracy by *display field-of-view pair* for each *display type*. Here error bars represent 95% confidence interval.

4.1.1 *Reading time.*

In terms of reading time, we found significant main effects for the independent variables *display field-of-view pair* ($F_{3,45}$ = 9.26, $p < 0.001$, η^2=0.38) (see Figure 4a). However, we did not find *display type* ($F_{1,15} = 0.41$, $p = 0.53$) to have an effect on reading time. As we found *display field-of-view pair* to have a significant main effect on reading time, we perform pairwise comparisons between *display field-of-view pairs*. We found *display* *field-of-view pair* 90, 180, and 270 are significantly (all $p < 05$) faster than *display field-of-view pair* 360. We found significant interactions of *display type* × *display field-of-view pair*($F_{3,45} = 6.51$, $p < 0.001$, $\eta^2 = 0.30$). As we found interaction effects of *display type* × *display field-of-view pair*, we further performed pairwise comparisons with Bonferroni corrections for each field-of-view. We found that Curve360 is significantly faster than Flat360 whereas Flat270 is significantly faster than Curve270. No other significant effect was found.

4.1.2 Reading Accuracy. In the text reading task, we did not find *display type* ($F_{1,15} = 0.01$, $p = 0.92$) and *display field-of-view pair* ($F_{3,45} = 0.74$, $p = 0.54$) to have an effect on reading accuracy (see Figure 4b). Furthermore, we did not find any interactions of *display type* × *display field-of-view pair* ($F_{3,45} = 0.77$, $p = 0.52$).

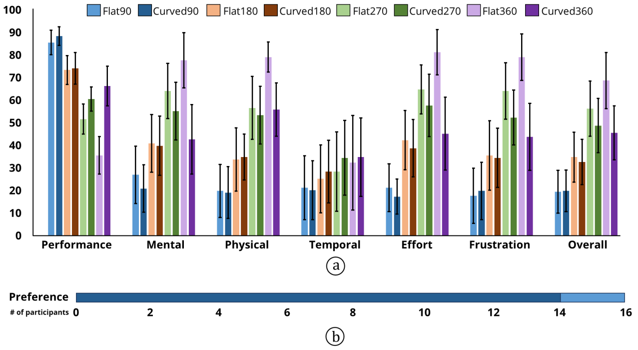


Figure 5: (a) NASA TLX scores for the reading task on each display. Error bars represent 95% confidence interval. (b) The figure also shows the most preferred display out of the eight displays for reading.

4.1.3 Preference Score. We used NASA Task Load Index (NASA TLX) [3] questionnaire to collect users' feedback on their effort, mental demand, physical demand, temporal demand, performance, frustration, and overall task load for each of the 8 displays for the text reading task.

A Friedman test on the text reading data revealed significant differences for eight out of the nine criteria across the eight displays. Specifically, significant differences were found for mental demand ($\chi^2(7, N = 16) = 63.01, p < 0.001$), physical demand ($\chi^2(7, N = 16) = 55.75, p < 0.001$), performance ($\chi^2(7, N = 16) = 70.17, p < 0.001$), effort ($\chi^2(7, N = 16) = 66.561, p < 0.001$), frustration ($\chi^2(7, N = 16) = 68.74, p < 0.001$), preference ($\chi^2(7, N = 16) = 73.15, p < 0.001$), fatigue ($\chi^2(7, N = 16) = 54.93, p < 0.001$), and overall workload ($\chi^2(7, N = 16) = 66.57, p < 0.001$) (see Figure 5a). However, no significant difference was observed for temporal demand ($\chi^2(7, N = 16) = 12.391, p = 0.09$).

For a detailed understanding, we conducted pairwise comparisons using the Wilcoxon signed-rank test, adjusting the α-levels from 0.05 to 0.0017 through Bonferroni corrections. The key findings from these comparisons are:

- **Performance:** Curve90 and Flat90 displayed the highest mean performance, significantly outperforming Curve270, Flat270, and Flat360. Curve180, Flat180, and Curve360 also exhibited superior performance compared to Flat360.
- **Physical Demand:** Flat360 was identified as the most physically demanding configuration, significantly more so than Curve90, Flat90, Curve180, and Flat180. Conversely, Flat90 and Curve90 were associated with the lowest physical demands.
- **Mental Demand:** In terms of mental demand, Flat360 was found to be significantly higher than Curve90, Flat90, Curve180, Curve270, and Curve360. Both Curve90 and Flat90 showed lower mental demands compared to Curve270 and Flat360.
- **Effort:** Effort analysis revealed that Flat360 required the most effort, significantly more than Curve90, Flat90, Curve180, Curve270, and Curve360. Curve90 and Flat90 were among the configurations requiring the least effort.
- **Frustration:** Frustration levels were highest for Flat360, significantly more than for Curve90, Flat90, Curve180, Curve360, and Flat270. Curve90 and Flat90 were among the least frustrating configurations.
- **Overall workload:** The overall workload was highest for Flat360, significantly more than for Curve90, Flat90, Curve180, Curve270, and Flat270. Curve90 and Flat90 were found to have the lowest overall workloads.

Overall, 14 out of 16 participants prefer the Curve90 display for reading comprehension tasks, while 2 out of the 16 participants prefer the Flat90 display (see Figure 5b). The NASA TLX score further supports higher preference for Curve90 as it has higher subjective rating based on performance, physical demand, mental demand, temporal demand, and effort.

4.2 Visual Text Search Results

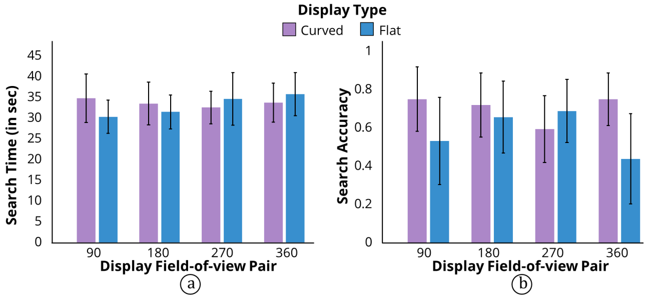


Figure 6: (a) Search time by *display field-of-view pair* for each *display type* (b) Search accuracy by *display field-of-view pair* for each *display type*. Here error bars represent 95% confidence interval.

4.2.1 Search time. In terms of search time, we did not find significant main effects for the independent variables *display field-of-view pair* ($F_{3,45} = 0.64$, $p = 0.60$) and *display type* ($F_{1,15} = 0.41$, $p = 0.53$) (see Figure 6a). We found significant interactions of *display type* × *display field-of-view pair* ($F_{3,45} = 2.89$, $p < 0.05$, η^2=0.16). As we found interaction effects of *display type* × *display field-of-view pair*, we further performed pairwise comparisons for each *display field-of-view pair*. For *display field-of-view pair* 90, we found that the flat display was significantly faster than curved display. No other significant effect was found.

4.2.2 Search Accuracy. In terms of accuracy, we found significant main effects for the independent variables *display type* ($F_{1,15} = 4.42$, $p < 0.05$, η^2=0.02) (see Figure 6b) where curved displays are more accurate than flat displays. However, display field-of-view pair ($F_{3,45} = 0.41$, $p = 0.74$) did not have an effect on search accuracy. We found no significant interactions of *display type* × *display field-of-view pair* ($F_{3,45} = 2.26$, $p = 0.08$). No other significant effects were found.

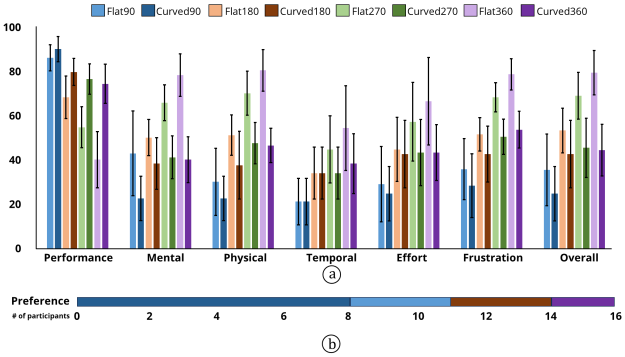


Figure 7: (a) NASA-TLX scores for the visual search task on each display. Error bars represent 95% confidence interval. (b) The most preferred display out of the eight displays for reading task.

4.2.3 Preference Score. We used NASA Task Load Index (NASA TLX) [3] questionnaire to collect users' feedback on their effort, mental demand, physical demand, temporal demand, performance, frustration, and overall task load for each of the 8 displays for the reading comprehension task.

A Friedman test on the reading comprehension data shows that there is a significant difference for eight out of the nine criteria: mental demand ($\chi^2(7, N = 16) = 65.15, p < 0.001$), physical demand ($\chi^2(7, N = 16) = 78.30, p < 0.001$), performance ($\chi^2(7, N = 16) = 75.93, p < 0.001$), temporal demand ($\chi^2(7, N = 16) = 73.87, p < 0.001$), effort ($\chi^2(7, N = 16) = 64.26, p < 0.001$), frustration ($\chi^2(7, N = 16) = 79.96, p < 0.001$) and overall workload ($\chi^2(7, N = 16) = 77.99, p < 0.001$) (see Figure 7a) across the eight displays.

For a detailed understanding, we conducted pairwise comparisons using the Wilcoxon signed-rank test, adjusting the α-levels from 0.05 to 0.0017 through Bonferroni corrections. The key findings from these comparisons are:

- **Performance:** Curve90 showed the highest mean performance, significantly outperforming other configurations such as Flat180, Flat270, and Flat360. Curve180, Curve270, and Curve360 also demonstrated superior performance compared to Flat270 and Flat360.
- **Physical demand:** Curve90 exhibited the lowest physical demand, significantly lower than that of Flat180, Flat270, Curve270, and Flat360.
- **Mental demand:** Curve90 also had the lowest mental demand compared to Curve270, Flat180, Flat270, and Flat360, indicating it is the least mentally taxing configuration.
- **Frustration:** Lower frustration levels were associated with Curve90 and Flat90 when compared to Flat270 and Flat360, making them the least frustrating options.
- **Overall workload:** Curve90 and Flat90 were associated with the lowest overall workload compared to other configurations, especially Flat270 and Flat360.

Overall, 8 out of 16 participants prefer the Curve90 display for reading comprehension tasks as shown in Figure 7b. Three participants preferred the Flat90 display, three participants preferred Curve180, and two participants preferred Curve360. The NASA TLX scores demonstrate Curve90 as the most preferred display as it consistently receives the highest rating for all the 7 subjective feedback criteria for the visual search task.

5 DISCUSSION

5.1 Text Readability

5.1.1 Flat vs. Curved Display. For the reading task, we observed that the *display type* (whether flat or curved) did not significantly influence both reading time and reading accuracy. This suggests that the inherent advantages or disadvantages of either being flat or curved might not affect reading tasks. However, an overwhelming number of participants prefer curved displays compared to flat displays as "text located at the corners are easier see" (P7, P2, P16), and the "display content is directed towards the user" (P8, P11). Furthermore, the subjective feedback from the NASA TLX questionnaire indicates that certain flat displays, especially those with wider display field-of-views (i.e., Flat360 and Flat270), are more mentally and physically demanding for users. However, few participants reported that the Flat displays provide a complete overview but require more effort to read the text that are located at the edge of the display.

5.1.2 Display field-of-view Pair. Our results highlight the importance of display field-of-view in influencing reading performance. Specifically, participants exhibited faster reading speeds for the *display field-of-view pair* 90 compared to the *display field-of-view pair* 360. The feedback from participants further justifies the superior performance of *display field-of-view pair* 90. The participants mentioned that they preferred the shorter *display field-of-view pair* as it "requires less body movement" (P4, P7) compared to wider *display field-of-view pairs.* Furthermore, the participants mentioned that for *display field-of-view pair* 90 "the entire text visible at a glance similar to reading a book" (P14). Additionally, the NASA TLX results further validate the superiority of shorter display field-of-views (Curved90, Flat90) having higher subjective feedback scores compared to wider display field-of-views (i.e., Flat360, Flat270). The longer lines on wider displays may impede reading because they make it harder for users to find the appropriate beginning of the next line after finishing one. This is a plausible explanation for the lower performance observed in the "Flat360" field-of-view, which could be attributed to the difficulty of managing longer lines of text without losing the reading flow. These results are consistent with prior work [9] which mentions that narrower paragraph widths lead to faster reading and better comprehension. While curved displays mitigate some of the issues by providing a more uniform viewing experience, large flat displays exacerbate angular distortion, making text harder to read as users need to move their gaze more frequently across the screen [46]. A potential solution to this issue could be breaking longer lines into multiple columns. By doing so, the text field-of-view would more closely resemble narrower text columns, reducing the need for extensive horizontal eye movements and making it easier for users to maintain their place while reading.

5.1.3 Summary. Curved displays were preferred over flat displays as they allow the users to read text that is located at any region of the display. The ergonomic advantage of a shorter display field-of-view 90 allows users to easily view and process information without significant head movement leading to higher user preference. Overall, Curve90 has the highest preference and subjective feedback rating while Flat360 has the lowest subjective feedback rating.

5.2 Visual Text Search

5.2.1 Flat vs. Curved Display. For the visual text search task, we observed that the curved display exhibited higher accuracy than flat displays. This suggests that the curvature of the display provides users with a more focused environment, leading to improved accuracy in visual search tasks. The participants mentioned that, unlike the flat display, it was easier to identify letters in the curved display as "the letters were facing the users" (P11) which made it "easier to find the letters" (P2, P3, P15). The curved display also emerged as the favorite display field-of-view based on user preference and subjective feedback scores.

5.2.2 Display field-of-view. In terms of the search tasks, our results indicate that there was no significant difference between the different *display field-of-views* for both search time and accuracy. This suggests that the spatial arrangement or field-of-view of the display might not play a pivotal role in influencing user performance for visual search tasks in the tested configurations. However, the subjective feedback from the NASA TLX questionnaire provides deeper insights into user preferences and perceived workload across different display field-of-views. Notably, certain displays like Flat360 and Flat270 were less preferred and had lower subjective performance ratings compared to Curve90, Flat90, Curve180, and Curve360. This indicates that users found flat displays with higher display field-of-views (such as Flat360 and Flat270) to be inefficient for visual search tasks. Their feedback suggested they preferred all the curved displays, particularly the Curve90 display for visual search tasks.

5.2.3 Summary. Curved displays lead to significantly more accurate visual task performance compared to flat displays. The shorter display field-of-view pair of 90 was preferred and had higher subjective rating than other display field-of-views. Similar to task 1, the results of task 2 also show Curve90 has the highest preference and subjective feedback scores while Flat360 has the lowest subjective feedback scores.

6 DESIGN IMPLICATIONS, LIMITATIONS, AND FUTURE WORK

We interpret key insights from our results and discuss the design implications for large displays in virtual reality. We also highlight the limitations that we observed during the study and discuss potential future works.

6.1 Design Implications

6.1.1 Optimal Display field-of-view. The results suggest that users were significantly faster in the reading comprehension task with shorter *display field-of-view pair* (i.e., 90, 180, and 270) compared to longest *display field-of-view pair* (i.e. Flat360 and Curved360). Subjective Feedback from both tasks shows a trend of increasing workload with the increase of *display field-of-view pair* value seen in Figure 5 and 7. Therefore, For reading tasks in VR, it would be beneficial for designers to optimize the display field-of-view to around 90 degrees to 180 degrees to enhance reading speed and reduce user workload, as evidenced by the workload comparisons shown in the study results for both tasks. The longer displays impede reading: this could be because longer lines make it harder to find the appropriate beginning of the next line after finishing a line. To improve readability on wider displays, app developers should consider breaking longer lines into multiple columns to enhance reading flow and comprehension.

For visual search tasks, there was no significant difference between the display field-of-views in terms of both search time and accuracy. This suggests that the spatial arrangement or field-of-view of the display might not play a pivotal role in influencing user performance for visual search tasks. Designers can have flexibility in choosing the display field-of-view based on other factors like user comfort or hardware constraints. However, preference and performance indicators favor curved displays, especially the Curve90 field-of-view, for their ergonomic benefits and lower associated user workload.

6.1.2 Flat vs. Curved Displays. Although the display type (flat or curved) showed no significant effect on reading time for the text reading task, curved displays exhibited higher accuracy in visual search tasks compared to flat displays. Additionally, across both tasks, curved displays consistently presented lower workload ratings (see figure 5, 7) than their flat counterparts for comparable display field-of-view pairs. VR developers can benefit from curved displays' advantages in providing a more engaging and less strenuous environment for VR applications, especially in tasks requiring focused visual attention.

6.1.3 Subjective User Workload and Display Characteristics. The NASA TLX results from both tasks indicate shows that wider display field-of-views (notably, Flat360 and Flat270), lead to higher workload and lower task performance. Display field-of-views with shorter viewing angles, particularly those with a field-of-view of 90 degrees, emerged as optimal choices for minimizing user workload and enhancing the overall experience. Therefore, based on the overwhelming preference for the Curve90 display compared to all other displays, VR developers integrate this display for various application scenarios.

6.2 Limitations and Future Work

Our study utilized a head-mounted device with a fixed field-of-view of 90 degrees. While this allowed us to simulate specific display configurations, it might not capture the full range of experiences users might have with devices offering a wider or narrower field-of-view. Future work can explore the impact of different field-of-view on user performance and preferences, especially as newer HMDs with varying field-of-view become available. Additionally, while the font size, style, and color contrast were carefully selected to ensure readability, the chosen font size of 50dmm might not be ideal for wider field-of-views. Although this factor might be negligible within a 90-degree field of view, it becomes significant as the display width varies greatly. Moreover, angular distortion on large flat displays is another factor that negatively impacts readability which we did not cover in our paper. While breaking longer lines into multiple columns could mitigate some readability issues, further investigation is needed. Future studies should explore the advantages of adjusting font sizes to minimize angular distortion and implementing narrower text columns for improved readability. The current work was conducted exclusively in VR. While VR offers the flexibility to simulate various display configurations without physical constraints, it's essential to understand how these findings translate to real-world physical displays. Future work could conduct comparative studies between VR and physical curved displays to gain insights into the direct applicability of our results in real-world scenarios. Our study, based on recommendations from prior research [6, 38], focused on the effects of display type and display field-of-view for a specific display curvature of 2000R. Future work could investigate whether our findings remain consistent across different display curvatures, especially as technology evolves and offers a broader range of curvature options. We set the interaction distance to a fixed 2m based on previous work [50, 51], which helped reduce the number of variables in our study. Future studies could investigate varying interaction distances to more thoroughly examine the impact of spatial differences on user experience and performance with curved displays. Our research focused on two specific tasks: text reading and visual text search. While these tasks offer valuable insights, future studies could expand the range of tasks, exploring interactions such as pointing, collaboration, viewing videos, or navigating interactive environments. Investigating the effect of *display field-of-view* will lead to a more holistic understanding of user interactions with curved displays.

7 CONCLUSION

In this paper, we investigated users' text reading and visual text search performance on large flat and curved displays with various field-of-views in VR. More specifically, we explored the effect of display field-of-view (with different viewing angles) and display types (flat or curved) on users' text reading and visual text search performance. We found shorter display field-of-view (particularly, viewing angle 90) display leads to significantly faster reading speeds compared to a wider display field-of-view (i.e., 360). Additionally, we showed that curved displays have significantly higher accuracy for visual search tasks. Overall, results suggest curved display with a viewing angle 90 (Curve90) is the most preferred display while flat display with a viewing angle 360 (Curve360) received the lowest subjective feedback rating for both text readability and visual search tasks. According to our findings, we presented guidelines for VR designers and provided suggestions on leveraging display specificities to improve users' performance for text readability and visual search on large virtual displays.

REFERENCES

[1] Sung Hee Ahn, Byungki Jin, Sanghyun Kwon, and Myung Hwan Yun. 2014. A research on curved display comparing to flat display regarding posture, tilt angle, focusing area and satisfaction. *Journal of the Ergonomics Society of Korea* 33, 3 (2014), 191–202. https://doi.org/10.5143/JESK.2014.33.3.191

[2] Ahmad Zamzuri Mohamad Ali, Rahani Wahid, Khairulanuar Samsudin, and Muhammad Zaffwan Idris. 2013. Reading on the Computer Screen: Does Font Type Have Effects on Web Text Readability?. *International Education Studies* 6, 3 (2013), 26–35. https://doi.org/10.5539/ies.v6n3p26

[3] TLX @ NASA Ames. 2023. Home. Retrieved January 15, 2023 from https://humansystems.arc.nasa.gov/groups/tlx/.

[4] Christopher Andrews, Alex Endert, Beth Yost, and Chris North. 2011. Information visualization on large, high-resolution displays: Issues, challenges, and opportunities. *Information Visualization* 10, 4 (2011), 341–355. https://doi.org/10.1177/1473871611415997 arXiv:https://doi.org/10.1177/1473871611415997

[5] Carmelo Ardito, Paolo Buono, Maria Francesca Costabile, and Giuseppe Desolda. 2015. Interaction with Large Displays: A Survey. *ACM Comput. Surv.* 47, 3, Article 46 (feb 2015), 38 pages. https://doi.org/10.1145/2682623

[6] Michael C Bartha, Paul Allie, and Doug Kokot. 2020. Field Observations of Placement for Large-Panel Flat and Curved Displays for Presbyopic and Prepresbyopic Computer Users. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 64. SAGE Publications Sage CA: Los Angeles, CA, 526–530. https://doi.org/10.1177/1071181320641119

[7] Patrick Baudisch, Nathaniel Good, and Paul Stewart. 2001. Focus plus Context Screens: Combining Display Technology with Visualization Techniques. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology* (Orlando, Florida) *(UIST '01)*. Association for Computing Machinery, New York, NY, USA, 31–40. https://doi.org/10.1145/502348.502354

[8] Michael L. Bernard, Barbara S. Chaparro, Melissa M. Mills, and Charles G. Halcomb. 2003. Comparing the effects of text size and format on the readibility of computer-displayed Times New Roman and Arial text. *International Journal of Human-Computer Studies* 59, 6 (2003), 823–835. https://doi.org/10.1016/S1071-5819(03)00121-6

[9] David Beymer, Daniel M Russell, and Peter Z Orton. 2005. Wide vs. narrow paragraphs: An eye tracking analysis. In *IFIP Conference on human-computer interaction*. Springer, 741–752. https://doi.org/10.1007/11555261_59

[10] Dhruv Bihani, A K M Amanat Ullah, Charles-Olivier Dufresne-Camaro, William Delamare, Pourang Irani, and Khalad Hasan. 2024. Exploring Pointer Enhancement Techniques for Target Selection on Large Curved Display. *Proceedings of the ACM on Human-Computer Interaction* 8, ISS (2024).

[11] Jeremy P. Birnholtz, Tovi Grossman, Clarissa Mak, and Ravin Balakrishnan. 2007. An Exploratory Study of Input Configuration and Group Process in a Negotiation Task Using a Large Display. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. Association for Computing Machinery, New York, NY, USA, 91–100. https://doi.org/10.1145/1240624.1240638

[12] Andre Büttner, Stefan M. Grünvogel, and Arnulph Fuhrmann. 2020. The influence of text rotation, font and distance on legibility in VR. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. 662–663. https://doi.org/10.1109/VRW50115.2020.00182

[13] Lizhou Cao, Chao Peng, and Jeffery T. Hansberger. 2019. A Large Curved Display System in Virtual Reality for Immersive Data Interaction. In *2019 IEEE Games, Entertainment, Media Conference (GEM)*. 1–4. https://doi.org/10.1109/GEM.2019.8811550

[14] Stuart K Card, Jock Mackinlay, and Ben Shneiderman. 1999. *Readings in information visualization: using vision to think*. San Francisco, California, Morgan Kaufmann Publishers, Inc.

[15] Marco Cavallo, Mishal Dholakia, Matous Havlena, Kenneth Ocheltree, and Mark Podlaseck. 2019. Dataspace: A Reconfigurable Hybrid Reality Environment for Collaborative Information Analysis. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 145–153. https://doi.org/10.1109/VR.2019.8797733

[16] Byeonghwa Choi, Seungbae Lee, Ja Eun Lee, Sungsu Hong, Jangdoo Lee, and Sungchul Kim. 2015. A study on the optimum curvature for the curved monitor. *Journal of Information Display* 16, 4 (2015), 217–223. https://doi.org/10.1080/15980316.2015.1111847

[17] Donghee Choi, Gyouhyung Kyung, Kyunghyun Nam, and Sungryul Park. 2019. Effects of display curvature, presbyopia, and task duration on visual fatigue, task performance, and user satisfaction. *Human factors* 61, 2 (2019), 273–287.

https://doi.org/10.1177/0018720818801407

[18] Kyungah Choi, Hyunjoo Bae, Sung-Wook Ju, and Hyeon-Jeong Suk. 2015. 53.2: Visual search and attention: What eye-tracking reveals about visual performance in the curved display. In *SID symposium digest of technical papers*, Vol. 46. Wiley Online Library, 798–801. https://doi.org/10.1002/sdtp.10315

[19] Sohan Chowdhury, A K M Amanat Ullah, Nathan Bruce Pelmore, Pourang Irani, and Khalad Hasan. 2022. WriArm: Leveraging Wrist Movement to Design Wrist+Arm Based Teleportation in VR. In *2022 IEEE Int. Symposium on Mixed and Augmented Reality (ISMAR)*. 317–325. https://doi.org/10.1109/ISMAR55827.2022.00047

[20] Andy Cockburn, Amy Karlson, and Benjamin B. Bederson. 2009. A Review of Overview+detail, Zooming, and Focus+context Interfaces. *ACM Comput. Surv.* 41, 1, Article 2 (jan 2009), 31 pages. https://doi.org/10.1145/1456650.1456652

[21] Robert Desimone and John Duncan. 1995. Neural mechanisms of selective visual attention. *Annual review of neuroscience* 18, 1 (1995), 193–222. https://doi.org/10.1146/annurev.ne.18.030195.001205

[22] Tilman Dingler, Kai Kunze, and Benjamin Outram. 2018. Vr reading uis: Assessing text parameters for reading in vr. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–6. https://doi.org/10.1145/3170427.3188695

[23] Berrin Dogusoy, Filiz Cicek, and Kursat Cagiltay. 2016. How serif and sans serif typefaces influence reading on screen: An eye tracking study. In *Design, User Experience, and Usability: Novel User Experiences: 5th International Conference, DUXU 2016, Held as Part of HCI International 2016, Toronto, Canada, July 17–22, 2016, Proceedings, Part II 5*. Springer, 578–586. https://doi.org/10.1007/978-3-319-40355-7_55

[24] Juan Carlo M Figueroa, Raul Alberto B Arellano, and Janeen Mikee E Calinisan. 2018. A comparative study of virtual reality and 2D display methods in visual search in real scenes. In *Advances in Human Factors in Simulation and Modeling: Proceedings of the AHFE 2017 International Conference on Human Factors in Simulation and Modeling, July 17–21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA 8*. Springer, 366–377. https://doi.org/10.1007/978-3-319-60591-3_33

[25] Jenny Gabel, Melanie Ludwig, and Frank Steinicke. 2023. Immersive Reading: Comparison of Performance and User Experience for Reading Long Texts in Virtual Reality. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–8. https://doi.org/10.1145/3544549.3585895

[26] Google. 2023. Firebase realtime database: store and SYNC data in Real time. Retrieved January 15, 2023 from https://firebase.google.com/products/realtime-database.

[27] Cameron Grout, William Rogers, Mark Apperley, and Steve Jones. 2015. Reading Text in an Immersive Head-Mounted Display: An Investigation into Displaying Desktop Interfaces in a 3D Virtual Environment. In *Proceedings of the 15th New Zealand Conference on Human-Computer Interaction* (Hamilton, New Zealand) *(CHINZ 2015)*. Association for Computing Machinery, New York, NY, USA, 9–16. https://doi.org/10.1145/2808047.2808055

[28] Faizan Haque, Mathieu Nancel, and Daniel Vogel. 2015. Myopoint: Pointing and Clicking Using Forearm Mounted Electromyography and Inertial Motion Sensors. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3653–3656. https://doi.org/10.1145/2702123.2702133

[29] BSEN ISO and BRITISH STANDARD. 2008. Ergonomics of Human-system Interaction – Part 304: User Performance Test Methods. *British Standards Institution* (2008).

[30] ISO ISO. 2000. 9241-9 Ergonomic requirements for office work with visual display terminals (VDTs)-Part 9: Requirements for non-keyboard input devices (FDIS-Final Draft International Standard), 2000. *International Organization for Standardization* (2000).

[31] Eng Tat Khoo, Tim Merritt, and Adrian David Cheok. 2008. Designing physical and social intergenerational family entertainment. *Interacting with Computers* 21, 1-2 (11 2008), 76–87. https://doi.org/10.1016/j.intcom.2008.10.009 arXiv:https://academic.oup.com/iwc/article-pdf/21/1-2/76/2164289/iwc21-0076.pdf

[32] Seina Kobayashi, Kei Kanari, and Mie Sato. 2021. An examination of view-settings for long texts in VR reading. In *ACM SIGGRAPH 2021 Posters*. 1–2. https://doi.org/10.1145/3450618.3469164

[33] Tanja Kojic, Maurizio Vergari, Sebastian Möller, and Jan-Niklas Voigt-Antons. 2022. Assessing User Experience of Text Readability with Eye Tracking in Virtual Reality. In *Virtual, Augmented and Mixed Reality: Design and Development*, Jessie Y. C. Chen and Gino Fragomeni (Eds.). Springer International Publishing, Cham, 199–211. https://doi.org/10.1007/978-3-031-05939-1_13

[34] Tanja Kojić, Danish Ali, Robert Greinacher, Sebastian Möller, and Jan-Niklas Voigt-Antons. 2020. User Experience of Reading in Virtual Reality — Finding Values for Text Distance, Size and Contrast. In *2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX)*. 1–6. https://doi.org/10.1109/QoMEX48832.2020.9123091

[35] Regis Kopper, Doug A. Bowman, Mara G. Silva, and Ryan P. McMahan. 2010. A human motor behavior model for distal pointing tasks. *International Journal of Human-Computer Studies* 68, 10 (2010), 603–615. https://doi.org/10.1016/j.ijhcs.2010.05.001

[36] Gyouhyung Kyung and Sungryul Park. 2021. Curved versus flat monitors: Interactive effects of display curvature radius and display size on visual search performance and visual fatigue. *Human Factors* 63, 7 (2021), 1182–1195. https://doi.org/10.1177/0018720820922717

[37] Haeng Jin Lee and Seong-Joon Kim. 2016. Factors associated with visual fatigue from curved monitor use: a prospective study of healthy subjects. *PloS one* 11, 10 (2016), e0164022. https://doi.org/10.1371/journal.pone.0164022

[38] Kyongho Lim, Xiaohua Li, and Yan Tu. 2019. Effects of curved computer displays on visual performance, visual fatigue, and emotional image quality. *Journal of the Society for Information Display* 27, 9 (2019), 543–554. https://doi.org/10.1002/jsid.768

[39] Chiuhsiang J. Lin, Betsha T. Abreham, and Bereket H. Woldegiorgis. 2019. Effects of displays on a direct reaching task: A comparative study of head mounted display and stereoscopic widescreen display. *International Journal of Industrial Ergonomics* 72 (2019), 372–379. https://doi.org/10.1016/j.ergon.2019.06.013

[40] Lars Lischke, Valentin Schwind, Kai Friedrich, Albrecht Schmidt, and Niels Henze. 2016. MAGIC-Pointing on Large High-Resolution Displays. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 1706–1712. https://doi.org/10.1145/2851581.2892479

[41] Jiazhou Liu, Arnaud Prouzeau, Barrett Ens, and Tim Dwyer. 2020. Design and Evaluation of Interactive Small Multiples Data Visualisation in Immersive Spaces. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 588–597. https://doi.org/10.1109/VR46266.2020.00081

[42] Jiazhou Liu, Arnaud Prouzeau, Barrett Ens, and Tim Dwyer. 2022. Effects of Display Layout on Spatial Memory for Immersive Environments. *Proc. ACM Hum.-Comput. Interact.* 6, ISS, Article 576 (nov 2022), 21 pages. https://doi.org/10.1145/3567729

[43] Meta. 2023. Meta quest 2: Advanced all-in-one VR headset. Retrieved January 15, 2023 from https://www.meta.com/gb/en/quest/products/quest-2.

[44] Sungchul Mun, Min-Chul Park, and Sumio Yano. 2015. Evaluation of viewing experiences induced by curved 3D display. In *Three-Dimensional Imaging, Visualization, and Display 2015*, Vol. 9495. SPIE, 23–30. https://doi.org/10.1117/12.2179436

[45] Nooree Na, Kyeong Ah Jeong, and Hyeon-Jeong Suk. 2015. Do curved displays make for a more pleasant experience?. In *Human Vision and Electronic Imaging XX*, Vol. 9394. SPIE, 421–426. https://doi.org/10.1117/12.2078102

[46] Miguel A Nacenta, Satoshi Sakurai, Tokuo Yamaguchi, Yohei Miki, Yuichi Itoh, Yoshifumi Kitamura, Sriram Subramanian, and Carl Gutwin. 2007. E-conic: a perspective-aware interface for multi-display environments. In *Proceedings of the 20th annual ACM symposium on User interface software and technology*. 279–288. https://doi.org/10.1145/1294211.1294260

[47] Mathieu Nancel, Olivier Chapuis, Emmanuel Pietriga, Xing-Dong Yang, Pourang P. Irani, and Michel Beaudouin-Lafon. 2013. High-Precision Pointing on Large Wall Displays Using Small Handheld Devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 831–840. https://doi.org/10.1145/2470654.2470773

[48] Jasminko Novak, Mattias Aggeler, and Gerhard Schwabe. 2008. Designing Large-Display Workspaces for Cooperative Travel Consultancy. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems* (Florence, Italy) *(CHI EA '08)*. ACM, USA, 2877–2882. https://doi.org/10.1145/1358628.1358777

[49] Bettina Olk, Alina Dinu, David J Zielinski, and Regis Kopper. 2018. Measuring visual search and distraction in immersive virtual reality. *Royal Society open science* 5, 5 (2018), 172331. https://doi.org/10.1098/rsos.172331

[50] Sungryul Park, Gyouhyung Kyung, Donghee Choi, Jihhyeon Yi, Songil Lee, Byeonghwa Choi, and Seungbae Lee. 2019. Effects of display curvature and task duration on proofreading performance, visual discomfort, visual fatigue, mental workload, and user satisfaction. *Applied ergonomics* 78 (2019), 26–36. https://doi.org/10.1016/j.apergo.2019.01.014

[51] Sungryul Park, Gyouhyung Kyung, Jihhyeon Yi, Donghee Choi, and Songil Lee. 2020. Curved TVs improved watching experience when display curvature radii approached viewing distances: Effects of display curvature radius, viewing distance, and lateral viewing position on TV watching experience. *Plos one* 15, 2 (2020), e0228437. https://doi.org/10.1371/journal.pone.0228437

[52] Yongmin Park, Jang Jin Yoo, Dongwoo Kang, and Sungjin Kim. 2015. Quantification model of proper curvature for large-sized curved TVs. *Journal of the society for information display* 23, 9 (2015), 391–396. https://doi.org/10.1002/jsid.348

[53] Yuan Yuan Qian and Robert J Teather. 2017. The eyes don't have it: an empirical comparison of head-based and eye-based selection in virtual reality. In *Proceedings of the 5th Symposium on Spatial User Interaction*. 91–98. https://doi.org/10.1145/3131277.3132182

[54] Elizabeth Quinn, Ian Stephen Paul Nation, and Sonia Millett. 2007. Asian and Pacific speed readings for ESL learners. *ELI Occasional Publication* 24 (2007), 74. https://www.victoria.ac.nz/__data/assets/pdf_file/0007/1713175/Speed-reading-2018-charactcontrolled.pdf

[55] Pei-Luen Patrick Rau, Jian Zheng, and Zhi Guo. 2021. Immersive reading in virtual and augmented reality environment. *Information and Learning Sciences*

122, 7/8 (2021), 464–479. https://doi.org/10.1108/ILS-11-2020-0236

[56] Pei-Luen Patrick Rau, Jian Zheng, Zhi Guo, and Jiaqi Li. 2018. Speed reading on virtual reality and augmented reality. *Computers & Education* 125 (2018), 240–245. https://doi.org/10.1016/j.compedu.2018.06.016

[57] Luz Rello, Martin Pielot, and Mari-Carmen Marcos. 2016. Make It Big! The Effect of Font Size and Line Spacing on Online Readability. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 3637–3648. https://doi.org/10.1145/2858036.2858204

[58] Arvind Satyanarayan, Daniel Strazzulla, Clemens N. Klokmose, Michel Beaudouin-Lafon, and Wendy E. Mackay. 2013. The CHI 2013 Interactive Schedule. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (Paris, France) *(CHI EA '13)*. Association for Computing Machinery, New York, NY, USA, 2987–2990. https://doi.org/10.1145/2468356.2479591

[59] Jürgen Scheible and Timo Ojala. 2005. MobiLenin Combining a Multi-Track Music Video, Personal Mobile Phones and a Public Display into Multi-User Interactive Entertainment. In *Proceedings of the 13th Annual ACM International Conference on Multimedia* (Hilton, Singapore) *(MULTIMEDIA '05)*. Association for Computing Machinery, New York, NY, USA, 199–208. https://doi.org/10.1145/1101149.1101178

[60] Lauren Shupp, Christopher Andrews, Margaret Dickey-Kurdziolek, Beth Yost, and Chris North. 2009. Shaping the display of the future: The effects of display size and curvature on user performance and insights. *Human–Computer Interaction* 24, 1-2 (2009), 230–272. https://doi.org/10.1080/07370020902739429

[61] Siddhanth Raja Sindhupathiraja, A K M Amanat Ullah, William Delamare, and Khalad Hasan. 2024. Exploring Bi-Manual Teleportation in Virtual Reality. In *2024 IEEE Conference Virtual Reality and 3D User Interfaces (VR)*. IEEE, 754–764. https://doi.org/10.1109/VR58804.2024.00095

[62] Henrik Haugom Solum. 2019. *Readability in Virtual reality, an investigation into displaying text in a virtual environment*. Master's thesis. NTNU. http://hdl.handle.net/11250/2617909

[63] Unity technologies. 2023. Unity Real-Time Development Platform | 2D, 3D, VR & AR Engine. Retrieved January 15, 2023 from https://unity.com/.

[64] Anne M Treisman and Garry Gelade. 1980. A feature-integration theory of attention. *Cognitive psychology* 12, 1 (1980), 97–136. https://doi.org/10.1016/0010-0285(80)90005-5

[65] Inna Tsirlin, Eve Dupierrix, Sylvie Chokron, Sabine Coquillart, and Theophile Ohlmann. 2009. Uses of Virtual Reality for Diagnosis, Rehabilitation and Study of Unilateral Spatial Neglect: Review and Analysis. *CyberPsychology & Behavior* 12, 2 (2009), 175–181. https://doi.org/10.1089/cpb.2008.0208 arXiv:https://doi.org/10.1089/cpb.2008.0208 PMID: 19361298.

[66] A K M Amanat Ullah, William Delamare, and Khalad Hasan. 2023. Exploring Users Pointing Performance on Large Displays with Different Curvatures in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics* (2023). https://doi.org/10.1109/TVCG.2023.3320242

[67] A K M Amanat Ullah, William Delamare, and Khalad Hasan. 2023. Exploring Users' Pointing Performance on Virtual and Physical Large Curved Displays. In *Proceedings of the 29th ACM Symposium on Virtual Reality Software and Technology* (Christchurch, New Zealand) *(VRST '23)*. Association for Computing Machinery, New York, NY, USA, Article 7, 11 pages. https://doi.org/10.1145/3611659.3615710

[68] Jacqueline Urakami, Henrique Matulis, Shio Miyafuji, Zhengqing Li, Hideki Koike, and Mark Chignell. 2021. Comparing immersiveness and perceptibility of spherical and curved displays. *Applied Ergonomics* 90 (2021), 103271. https://doi.org/10.1016/j.apergo.2020.103271

[69] Chunxue Wei, Difeng Yu, and Tilman Dingler. 2020. Reading on 3D Surfaces in Virtual Environments. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 721–728. https://doi.org/10.1109/VR46266.2020.00095

[70] Marina Zannoli and Martin S Banks. 2017. The perceptual consequences of curved screens. *ACM Transactions on Applied Perception (TAP)* 15, 1 (2017), 1–16. https://doi.org/10.1145/3106012