Page-Turning Techniques for Reading Interfaces in Virtual Environments

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ABSTRACT

Virtual Reality (VR) environments offer new ways and formats to consume and process information. Despite multimedia offerings, most information remains to be presented via text. VR has the potential to deliver immersive reading experiences while compensating for some of the drawbacks of rather static e-books. To allow readers to step into virtual books, we developed a 3D reading environment with three page-turning techniques for VR. Readers either move the camera position from page to page or control the page flow as positioned in a sequential or radial arrangement. Results from a user study with 18 participants show that moving pages is perceived as more comfortable than moving the camera position while allowing for higher fluency and reading speeds. Linear page movements support readers' focus on a single page whereas the radial arrangement enables readers to jump between pages quickly. Our findings inform the design of immersive reading experiences in VR.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Human computer interaction (HCI)**; User studies.

KEYWORDS

Reading UI; Page-Turning; Virtual Reality; Immersive Reading.

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1 INTRODUCTION

Reading is one of the most common and prominent ways to acquire knowledge and is also taken up as a leisure activity. New technologies have pushed the boundaries of reading, with mobile devices and e-books re-defining how, where, and what we read. Electronic documents are read on a plethora of gadgets and provide portability without weight restrictions. Content is instantly accessible, from anywhere. And devices allow readers to customize their reading interface in the form of display parameters, *e.g.,* brightness, but also text parameters, such as font size, family, and style, some of the significant advantages of paper. Libraries and other content providers have been racing to digitize documents to provide online document access to readers around the world. Compared to print-books, however, e-books lack tactability and tangibility, which poses particular challenges to readers to orient themselves and effectively navigate the book [32]. The intangible nature of e-books is often said to lack the *feel* of paper, which as a result prevents readers from efficiently flipping through them. Such exploration is crucial for readers to get an idea of a book's contents and volume, and e-books struggle to provide readers with an effective overview prior to or a sense of progress during reading.

Virtual Reality (VR) with its immersive nature, on the other hand, provides new opportunities to address some of these drawbacks and to design novel reading experiences. Research in this field ranges from making news accessible for low-vision users [31] to designing effective text displays [5, 13, 30] and creating immersive reading interfaces [11, 24]. Such computer-generated 3D environments allow us to extend the 2D nature of e-books, to create interfaces that spatially immerse the reader into a story, and to provide novel text interactions.

One of the most common and critical interactions during reading is navigating text. While electronic displays provide a range of navigation methods, including search and scrolling techniques,

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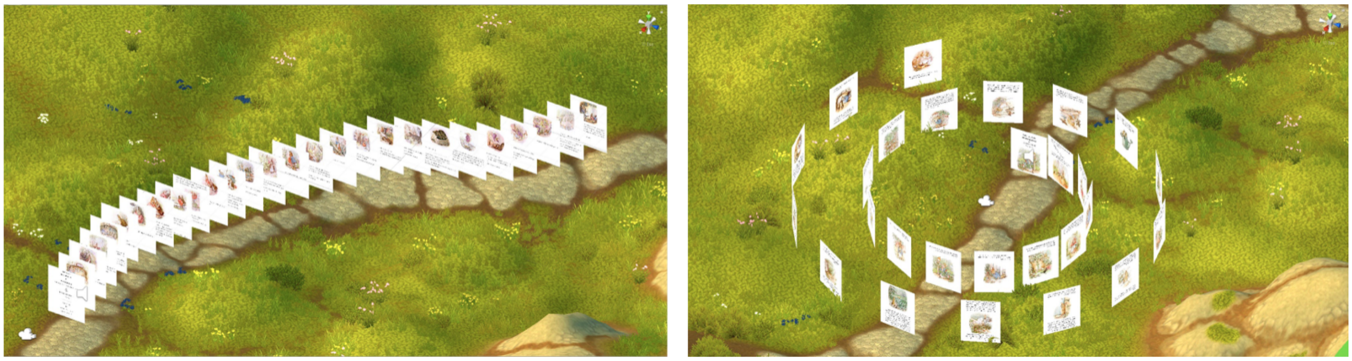

Figure 1: We compare three page-turning techniques in VR by either 1) moving the camera (*i.e.*, reader walks from page to page), 2) moving pages in a linear fashion towards the reader (both depicted on the *left*), or 3) moving pages arranged in a spiral around the user in a radial manner (*right*). The camera symbol indicates the reader's position in VR.

reading interfaces often feature prominent elements from printed books, such as page-turning. In the case of physical books, turning over pages is often an anticipatory act [4] that simultaneously conveys an overview as well as a sense of progress.

To allow readers to virtually step into a 3D reading experience, and at the same time overcome the drawbacks of 2D e-books, we designed a virtual reading environment with three page-turning techniques for navigating books in VR. The techniques provide control over either the reader's position or the movement of the pages as arranged in either a linear fashion or surrounding the reader radially (see Figure 1). To assess the effects of these three page-turning techniques on the reading experience, we conducted a user study with 18 participants with the goal of eliciting interface characteristics that allow users to naturally interact with reading content while providing comfort, focus, and supporting an immersive reading experience. This work's, therefore, is twofold:

(1) We present three page-turning techniques for reading interfaces in VR.
(2) We report findings and implications from a user study on the effects of page-turning in VR regarding reading speed, general comfort, sense of presence, and readability.

VR devices and applications are increasingly making their way into the consumer domain. Effective text display is a vital component of application instructions, gameplay, and more recently also news consumption [31]. While much research has been conducted around textual interfaces on 2D displays, little work has been done on the user's reading experience in immersive, 3D virtual environments. Our work contributes to this body of knowledge by focusing on text navigation techniques.

2 RELATED WORK

Early reading studies compared reading on paper to reading on digital screens finding that screens generally slow readers down [1, 19]. This seems to be the case even for readers experienced with screens [10]. Reasons for the decreased performance are often device properties, such as the quality of the screen but also design parameters, such as text display and page layout. The hardware has been significantly improved in recent years, and various studies have produced guidelines on how to optimize text legibility, both on the web [22] and hand-held devices [9]. Such devices also allowed the experimentation with novel reading methods, such as rapid serial visual presentation (RSVP), where a text is displayed word-by-word in one focal spot. These experimental reading interfaces have been deployed on mobile devices [7] and also been combined with eye-gaze input to control the reading flow [6].

With the commercialization of e-book readers with e-ink technology, legibility became comparable to paper reading [25], but issues of usability remain, especially with regard to navigation [17] and the missing element of tangibility [32]. Pearson *et al.* [20] provide guidelines for e-reader design, noting the 'Next' button to provide the most commonly used function, which, therefore, requires special design attention. Meanwhile, efforts are being undertaken to extend the reading experience to the third dimension.

2.1 3D Reading Interfaces

Reading interfaces have been subject to research in various mixed reality applications allowing text to be rendered dynamically and in different locations. Rzayev [23] and colleagues, for example, investigated text placements in head-mounted display as an overlay over the real world. Wei *et al.* [30] looked at reading interfaces in VR where text can be warped over 3-dimensional shapes. Chu *et al.* [33] presented a 3D page turning prototype to augment the reading experiences of digital libraries. The software turns PDFs or e-book files into sequences of images and animates three-dimensional page-turns following the principle of skeuomorphism. Similarly, Card *et al.* [2] created *3Book*, a 3D electronic codex book containing 300 scanned pages with page-turning capabilities. While these prototypes live on a 2D screen, they resemble first explorations of how to present and allow the reading of large books on electronic displays.

With the recent uptake in VR devices, few studies have focused on reading activities in virtual environments. Sousa *et al.* [27] investigated ambient lighting conditions for when radiologists analyze and interpret images. Using VR headsets, they report diminishing the effects of unsuitable ambient conditions. Grout *et al.* [11] focused specifically on reading tasks with head-mounted displays examining different aspect ratios and compared plane vs. curved displays. Dingler *et al.* [5] investigated text parameters for reading in VR eliciting guidelines for text size, convergence, view box dimensions and text positioning. Other investigations have lead to reading interfaces for augmented reality on head-mounted displays [23].

2.2 Page Navigation

For reasons of legibility and due to limitations in screen size, texts are broken down into pages. Pagination, is, therefore, commonly used in web interfaces as well as on mobile devices and e-books. It is traditionally thought of as a layout challenge in which a document is broken up into pages suitable for printing. While this generally also holds true for electronic displays, it also portions the reading content into digestible chunks. Page-turning is, therefore, a common navigational activity when reading. According to Dillon [4] it is often an anticipatory act: to ensure continuity of the reading flow, the reader grabs the corner of a page long before reading the last word on the page. In contrast, page-turning on electronic displays is a discrete rather than a continuous action. While this way of turning seems efficient, users tend to briefly lose the connection with the text, and their interaction becomes interrupted [16]. To address this issue, page-turns are often animated, which adds skeuomorphism to digital reading interfaces by making the reading interface resemble its real-world counterpart. Animated transitions create a visual continuity between object changes and are, therefore, a popular design choice for switching between views [8]. Liesaputra and Witten [18] give a detailed account of creating a realistic electronic book, including functions, such as visual location cues and page-turning. Their focus on skeuomorphism led them to implement a realistic page-turn animation to prevent readers from briefly losing contact with the text and, therefore, from interrupting the reading process.

Vanderschantz *et al.* [29] identified the following six page-turning methods by inspecting a range of contemporary e-readers: arrows, swipe, page curl, tap/touch, slider, and page mini view. Some methods are derived from page-turning in a physical book, whereas others resemble rather abstract ways of navigation by using buttons and touchpoints. Tap/touch was mostly preferred by their study participants as it was perceived as an easy, fast, and efficient way of turning pages. Mini view allowed readers to preview subsequent page numbers and content and was hence deemed more appropriate for reading academic information. For pleasure reading, participants preferred swipe as they enjoyed the animation. In consequence, the page-turning techniques we devised are designed so that pages can be directly turned (by the press of a controller button) with animation to engage readers and a preview aspect in at least one of our techniques.

While scrolling has been established as a prominent alternative to pagination, it tends to break with the convention of traditional books and provides an inherently different reading experiences more associated with online content and in particular mobile searches [15]. Pagination has been a particular focus of research on search engine results pages where it tends to be outperformed by scrolling [3]. While scrolling supports scanning tasks, Kim *et al.* [15] found that pagination results in more thorough reading. But this work has not been applied to immersive, virtual environments. Prior work, in general, has predominantly focused on interface design for electronic reading interfaces in 2D. A lot of the page-turning discussions revolve around efficiency and realism. Virtual environments add an additional dimension and, therefore, open up the design space for spatial page arrangements. We, therefore, set out to explore the effects of different page-turning techniques in VR and answer the following research questions:

- **RQ1:** What are effective ways of page-turning in VR? and
- **RQ2:** How might these affect the reading experience?

3 PAGE-TURNING TECHNIQUES

In the following, we lay out the design considerations that lead to three different page-turning techniques in VR and describe the implementation of our apparatus.

3.1 Design

With the intent to build immersive reading experiences for in-depth reading, the techniques we focus on incorporate **page-by-page turning** rather than scrolling, for example. This is motivated by the study by Kim *et al.* [15], which showed page-turning leads to more thorough reading.

As a general **environment** we opted for a design that is soothing in nature, without majorly distracting features, and which provides suitable lighting. The scene comprises different elevations to allow users to get a full view of it.

The **spatial arrangements** of the pages is meant to convey a feeling of position and progress: characteristics that are often lost with e-books where reading progress tends to be explicitly displayed, for example, by page numbers or a through progress bar. We designed an interface where it is possible to gain an overview of the entire book while allowing to locate the reader's position. The pages are evenly spread out along a path in the virtual environment. We devised a Unity script to read a PDF document and position its pages along the path (see Figure 1, *left*). Each page is rendered as a 2D image in the 3D scene. We ensured that pages are rendered without distortions.

For page-turning, we based our work on observations made by Tajika and colleagues [28] and their definition of three main page-turning types: 1) turning pages one by one, 2) flipping through several single pages at a time, and 3) *leafing*, *i.e.,* turning multiple pages at once. Consequently, we devised three page-turning techniques to explore these different features: the first provides the reader with six degrees of freedom (DoF) in the form of controls over the **moving camera** position. The reader can freely walk around the environment and inspect each page in the scene (i.e., the 3D environment) by walking up to it, one by one. The pages handle collisions, so the reader can walk up to but not through them. A controller button allows users to remove the current page from the scene and walk to the next by using the controller. The reader can walk backwards as well to go to a previous page. A back button brings the previously read page back onto the scene. Readers can get an overview of their reading progress by stepping sideways and peak along the row of pages.

The second technique (**moving pages linearly**) provides 3 DoF by removing the user's control over the camera position. It solely allows readers to page forward or backward while the camera remains fixed in one spot. Just like for the previous technique, the pages are laid out evenly on a single linear path. Once the first page is turned, it is removed from the scene and the entire queue of remaining pages moves *linearly* towards the user in an animated way. The next page stops in the same place in front of the reader. Paging backwards reverses this process and adds the last page back to the scene. Since the pages are positioned along a curved path with different elevations, the reader is able to see the page queue in the background thus being able to retain a sense of progress. The idea behind this technique is to eliminate the reader's need to position the camera optimally in front of the next page and to support the reading flow.

The third page-turning technique (**moving pages radially**) is devised to support page flipping and leafing: It also fixes the camera position in one place but arranges the pages in concentric circles around the reader expanding outwards (see Figure 1, *right*). The idea behind this technique is that several pages are in the reader's field of view at the same time allowing to jump back and forth through head rotation. Paging forward rotates the spiral counter-clockwise and moves the next page in front of the reader with an animation. Paging backwards moves the spiral clockwise thus centering the previous page. Previously read pages start being removed from the scene entirely after six page-forwards, which places the most previous page right behind the reader. The pages are spaced in a way that the gaps between them allow for a glimpse at the concentric circles behind.

3.2 Apparatus

We implemented the VR reading environment using Unity3D (a 2018 release). As hardware platform we used the Oculus Rift CV1 system, which consists of a head-mounted display (HMD), a pair of controllers, and two infrared sensors for tracking the position of the headset and the controllers. The screen resolution of the HMD was 1080×1200 while the field of view(FoV) 110 degrees in the diagonal. The virtual environment ran on an Alienware Aurora R7 with an Intel Core i7-8700K CPU@3.70GHz and NVIDIA GeForce GTX 1080. The camera position in relation to the first page was determined by the font angular size to the text within the recommended range of common LogMAR scale sizes [21]: 1.4°. This value also falls into the range suggested by Dingler *et al.* [5].

4 METHOD

To assess the effectiveness and user experience of these three variants of paging through virtual books, we conducted the following experiment in our lab:

4.1 Study Design

In a repeated-measure study we compared the following three pagination techniques:

(1) **Moving camera**: the book pages expand sequentially throughout the scene, the user moves the camera from page to page.
(2) **Moving pages (linear)**: the book pages expand sequentially throughout the scene, the pages move to the user's position upon interaction.
(3) **Moving pages (radial)**: the book pages expand radially around the user, the pages move to the user's front position upon interaction.

As reading material we selected three children's books with comparable difficulties with an average Flesch Reading Ease score of $M = 79.9 (SD = 1.2)$, *i.e.*, easy to read (Flesch-Kincaid Grade Level: $M = 5.4 (SD = 0.2)$, *i.e.* 5th grade). The texts originated from the same author and comprised both text ($M = 1114 (SD = 156.3)$ words) and sketches ($M = 26.7 (SD = 0.6)$) with an average of $M = 26.7 (SD = 0.6)$ pages. Assuming a reading speed of 200 words per minute (wpm) would, therefore, require an average reader to spend about 5 – 6 minutes reading through each story. We selected childrens' books to emphasize the playfulness of VR environments and to allow users to focus on the story. To control for potential differences in text content and user interests, conditions and reading materials were allocated in a Latin square design. To prevent sequence effects we counterbalanced the conditions using Latin square as well. As dependent variables we measured participants' reading speed and administered a questionnaire about a) reading comfort, b) the sense of presence, and c) aspects of readability.

We assessed **comfort** using a subset of six simulator sickness measurements [14]: fatigue, boredom, headache, dizzy, dry eyes, and general discomfort (see Table 1). Each aspect was rated on a 7-point Likert-style scale with 1=*no symptoms* and 7=*severe symptoms*. We measured the **sense of presence** using an adapted version of Slater *et al's* presence questionnaire [26] assessed through six statements on the sense of *being there* and immersion (see Table 2). The third part of the questionnaire focused on aspects of **readability** and comprised five statements assessing reading comfort, ease of reading, perceived reading speed, subjective comprehension, and distraction (see Table 3). Similar to the statements about *presence*, the response to each of these statement ranged from 1 to 7 on a Likert-style rating scale with 1=*I completely disagree* and 7=*I completely agree*. The last two questions on the questionnaire were open-ended questions to collect qualitative feedback inquiring what the participants liked/disliked about the particular pagination condition.

4.2 Participants

We recruited 18 participants (7 female, 11 male) through university mailing lists, billboards, and our social networks. Their average age was $M = 22$ ($SD = 1.6$) years. Nine indicated English to be their first language, seven Chinese, and two French. All participants were fluent in English as required by the University. Eight participants had corrected vision wearing glasses or contact lenses. Most of them indicated to regularly read on printed media (12), on a PC (10), phone (10), tablet (5), or e-reader (3). The majority (15) had used VR once or twice before, one said he frequently used VR, another one owned a VR set, while two participants had never used VR before. With regard to reading habits, three participants indicated to occasionally read (1-2 times a week) in their spare time, five said they read sometimes (3-4 times a week), four participants read often (around 5 times a week) and six daily.

4.3 Procedure

We welcomed participants to our lab and explained the purpose of the study. We provided a plain language statement and asked participants to sign the consent form. Following an introduction of the Oculus Touch controller, participants put on the headset and

Symptom	Moving Camera	Moving Pages (linear)	Moving Pages (radial)	Test Statistic
Fatigue	M=3, Mdn=2.5 (SD=1.88)	M=2.22, Mdn=2 (SD=1.4)	M=3.33, Mdn=3 (SD=1.75)	**p = 0.031**
Boredom	M=2.28, Mdn=2 (SD=1.64)	M=2.17, Mdn=1.5 (SD=1.79)	M=2.83, Mdn=2 (SD=2.01)	*p > 0.05*
Headache	M=2.5, Mdn=1 (SD=1.79)	M=1.78, Mdn=1 (SD=1.22)	M=2.06, Mdn=1 (SD=1.66)	*p > 0.05*
Dizzy	M=3.28, Mdn=3 (SD=1.78)	M=2.61, Mdn=2.5 (SD=1.46)	M=3.28, Mdn=3 (SD=1.93)	*p > 0.05*
Dry Eyes	M=2.89, Mdn=3 (SD=1.84)	M=2.44, Mdn=2 (SD=1.58)	M=3, Mdn=3 (SD=1.91)	*p > 0.05*
General Discomfort	M=3.11, Mdn=2.5 (SD=1.88)	M=2.33, Mdn=2 (SD=1.28)	M=3.22, Mdn=3 (SD=1.7)	***p = 0.028***

Table 1: Subjective assessments of participants' *general comfort* on a 7-item Likert-style scale where 1=*no symptoms* and 7=*severe symptoms.*

adjusted the lenses until an initially displayed text could be viewed clearly. Those with corrected vision kept wearing their contacts or glasses. Then, the experimenter launched the first condition according to a counterbalanced design. Participants were instructed to read through the entire book and were informed that a comprehension test awaited them at the end to ensure participants read the texts attentively (we did not use it as an actual measure for comprehension). After finishing the reading task, participants removed the headset and were asked to fill in the three-part questionnaire on paper assessing comfort, sense of presence, and readability. We encouraged participants to rest after each condition before moving on to the next condition in which we repeat the same procedure. Upon completion of all three conditions, we administered a demographic questionnaire along with some qualitative questions about the experience with each pagination technique. The study took about 60 minutes to complete, and we compensated participants with 10 AUD gift vouchers.

5 RESULTS

In the following, we report the results of our study in four parts in accordance with our measures. Due to the non-parametric nature of the collected data we applied Friedman tests as omnibus tests with subsequent pairwise comparisons using Wilcoxon signed-rank tests. To account for the three experimental conditions, we adjusted the level of significance to $p = .017$ using Bonferroni correction in those post-hoc tests.

5.1 Comfort

There was a statistically significant difference in *general discomfort* depending on the pagination technique used, $\chi^2(2) = 7.143, p = 0.028$. Post-hoc tests revealed a statistically significant difference between linear *vs.* radial page movement ($Z = -2.543, p = 0.011$) with moving pages linearly being perceived more comfortable than being surrounded by them.

The different pagination conditions yielded a statistically significant difference in *fatigue* levels ($\chi^2(2) = 6.933, p = 0.031$) with moving pages linearly inducing less severe symptoms of fatigue than radial movements ($Z = -2.55, p = 0.011$).

There was no statistically significant difference in rated *boredom*, *headache*, *dizzy*, or *dry eyes* between conditions. Table 1 contains all self-assessment values with regard to general comfort.

Statement	Moving Camera	Moving Pages (linear)	Moving Pages (radial)	Test Statistic
In the computer generated world I had a **sense of "being there"**.	M=5.5, Mdn=6 (SD=1.58)	M=5.56, Mdn=6 (SD=1.15)	M=5.28, Mdn=5.5 (SD=1.71)	*p > 0.05*
Somehow I felt that the virtual world **surrounded** me.	M=5.39, Mdn=6 (SD=1.5)	M=5.67, Mdn=6 (SD=1.23)	M=4.83, Mdn=5 (SD=1.76)	***p = 0.007***
I felt like I was **just** perceiving **pictures**.	M=3.22, Mdn=3 (SD=1.67)	M=3.5, Mdn=4 (SD=1.2)	M=3.61, Mdn=3.5 (SD=1.88)	*p > 0.05*
I felt **present** in the virtual space.	M=5.39, Mdn=6 (SD=1.46)	M=5.39, Mdn=6 (SD=1.34)	M=4.78, Mdn=5 (SD=1.44)	***p = 0.034***
I had a **sense of acting** in the virtual space, rather than operating something from outside.	M=5.22, Mdn=6 (SD=1.77)	M=4.83, Mdn=5 (SD=1.62)	M=4.06, Mdn=4.5 (SD=1.77)	***p = 0.05***
I was not **aware** of my real environment	M=4.72, Mdn=5 (SD=1.93)	M=5.22, Mdn=6 (SD=1.77)	M=5.5, Mdn=6 (SD=1.69)	*p > 0.05*

Table 2: Subjective assessments of participants' *sense of presence* on a 7-item Likert-style scale where 1=*completely disagree* and 7=*completely agree.*

5.2 Presence

A statistically significant difference could be found with regard to the feeling of the environment *surrounding* the user, $\chi^2(2) = 9.880, p = 0.007$. Post-hoc tests, however, did not yield a statistically significant difference between the pagination techniques.

There was further a significant difference in terms of *presence in the virtual space*, $\chi^2(2) = 6.760, p = 0.034$. Post-hoc tests did not yield a difference between conditions.

We also found a significant difference with regard to a *sense of acting in the virtual space*, $\chi^2(2) = 5.930, p = 0.05$, but no differences between individual conditions.

The omnibus test yielded no statistically significant difference between conditions with regard to the *sense of being there*, *just perceiving pictures*, and *not being aware of users' real environment*. Table 2 lists all values with regard to their sense of presence.

5.3 Readability

There was a statistically significant difference in *reading comfort* depending on the pagination technique, $\chi^2(2) = 5.804, p = 0.05$. Post-hoc tests, however, yielded no difference.

There was no statistically significant difference with regard to *ease of reading*, *reading very fast*, *perceived understanding*, and *distraction* (see Table 3).

5.4 Reading Speed

A repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean reading speed differed significantly between the three pagination techniques ($F(1.821, 30.960) = 4.337, p = 0.021$). Post-hoc tests using the Bonferroni correction revealed that moving the camera resulted in significantly longer reading time ($M = 8.07min, SD = 2.51$) as compared to the linear page moving technique ($M = 6.83min, SD = 2.68$), $p = 0.05$, and the radial page movement ($M = 8.09min, SD = 1.75$), $p = 0.028$.

5.5 Qualitative Feedback

Building on the results of our quantitative analysis, we analyzed the participants' open-ended responses. We applied a thematic analysis clustering participants' comments around elements of the reading experience, such as comfort, presence, and readability.

5.5.1 Comfort. For the pagination technique, in which the camera moved, the following participants positively commented on an increased sense of control; "*It is more comfortable and way less dizzy. It feels like I was walking around the road and it can be easier*

Statement	Moving Camera	Moving Pages (linear)	Moving Pages (radial)	Test Statistic
Reading this text was very **comfortable**.	M=3.94, Mdn=3.5 (SD=1.77)	M=4.89, Mdn=5 (SD=1.75)	M=3.94, Mdn=3 (SD=2.07)	$\boldsymbol{p = 0.05}$
The text was very **easy to read**.	M=4.61, Mdn=5 (SD=1.82)	M=5.11, Mdn=5 (SD=1.75)	M=4.56, Mdn=4.5 (SD=1.79)	$p > 0.05$
I felt I was reading very **fast**.	M=4.78, Mdn=5 (SD=1.22)	M=5.5, Mdn=5.5 (SD=1.15)	M=4.78, Mdn=5 (SD=1.8)	$p > 0.05$
I **understood** the text content well.	M=5.33, Mdn=5.5 (SD=1.19)	M=5.5, Mdn=6 (SD=1.25)	M=5.61, Mdn=6 (SD=1.09)	$p > 0.05$
The text presentation **distracted** me from the content.	M=3.28, Mdn=3 (SD=1.57)	M=2.5, Mdn=2 (SD=1.34)	M=3.11, Mdn=3 (SD=1.61)	$p > 0.05$

Table 3: Subjective assessments of participants' *readability scores* on a 7-item Likert-style scale where 1=*completely disagree* and 7=*completely agree.*

to control the way I read." (P06). Even though participants controlled pagination in all conditions, moving the camera resulted in a higher level of autonomy as a reader; "*The sense of control is better in this environment. I can walk to the pages instead of them coming towards me.*" (P08). Browsing the pages one by one allowed users to focus, whereas being presented with multiple pages at once (*i.e.*, moving pages radially caused discomfort; "*This reading environment was a little more discomforting as the mind was travelling to different places and was not being able to concentrate on one single task. I would prefer to see and concentrate on one page at a time.*" (P13). More generally, participants indicated that the need to provide active input to adjust the reading location is likely to be uncomfortable when reading larger texts; "*This is something I would not want when I am reading something. I would want my reading to be seamless without much effort to focus on adjusting my screen after every page.*" (P13).

5.5.2 Presence. Based on our participants' comments, a careful balance between story content (*i.e.*, pages on display) and background material is required to give rise to reader presence. As such, participants commented predominantly negatively on the presence experience in the third condition (pages were positioned in a circle around the reader), which effectively occluded the VR ambience. An exemplary comment stated; "*When reading, the surrounding environment is completely obscured by the reading page, which does not improve the reading comfort and immersion*" (P04). In contrast, the other two conditions allowed participants to 'move' through the story line in a more linear fashion while retaining the ability to experience more of the environment. As stated by P01; "*Feels like it brings me into the context and I am standing there to see how the story is going. And I do not care [about] anything happening outside this virtual world.*". This increase in presence increased the experienced immersion while not overloading the participants with content; "*I think I can read the book carefully in this environment, and it creates a relaxed atmosphere.*" (P12).

5.5.3 Readability. The different conditions impacted the readability of the text in different ways. Most notably, the following participants voiced their appreciation for the radial presentation of pages due to the ability to quickly return to the previous page; "*If you need to re-read the content of the previous page, just look around and look more comfortable than the way you move the page back and forth*" (P04). Similarly, the radial design allowed participants to obtain a sense of their reading progress; "*You could see flipping of pages and get a sense of what you can expect to read/see and how much of the reading is left to read*" (P13). In contrast, the more linear pagination designs allowed for an increased focus on the page on display; "*Being able to easily focus on the content and jump reading.*" (P04). Furthermore, the fact that participants did not have to actively move in the moving pages conditions was appreciated; "*The automatic appearance of next reading pages promotes reading fluency and reading efficiency.*" (P09). These comments highlight how the different designs all have their own unique (positive) impact on readability – potentially explaining the lack of significant differences in the participants' subjective assessment of the readability in the respective conditions.

Finally, we asked participants to rank the three pagination techniques according to their preference: moving pages in a linear way was ranked highest with ten first votes, five participants ranked the radial interface and three rated the moving camera as top candidate.

6 DISCUSSION

Virtual Reality allows for the presentation of text and other media in new ways. Navigating between pages has so far not been extensively explored in VR despite the fact that page turning has been identified as a critical element in analogue book reading [4]. The presented prototypes and study contributes an assessment of the effects and possibilities of page-turning techniques in VR. Our study showed that moving pages linearly was the most comfortable way of page-turning compared to the other two techniques. Moving pages in a straight line also induced less symptoms of fatigue than radial movements while increasing the sense of presence. Since the camera position was fixed there were less indicators of motion sickness compared to the moving camera condition, which is in line with previous research [12]. On the other hand, participants exhibited a tendency to feel a greater sense of acting in the virtual space when moving the camera rather than the pages, which is likely due to the 6 DoF provided in this condition.

Both the linear and radial page moving techniques lead to shorter reading times than moving the camera, which is hardly surprising given the time it takes to walk up to the next page. Moving pages was commented on to increase reading fluency and efficiency as the viewpoint did not need to be adjusted and pages could be quickly flipped back and forth. Participants indicated that they were better able to focus when pages where moved linearly as they could focus on one page at a time as opposed to the radial method where multiple pages might have been in view at once. The radial page arrangement, however allowed users to quickly jump back and forth between pages as they could choose to either move the page or rotate their head.

Our results highlight a number of significant differences between the investigated pagination design techniques. They exhibit some implications on the design of page-turning techniques in VR, which are summarized as follows:

- Moving pages towards the user supported the reading flow and reduced the risk of motion sickness symptoms induced by locomotion.
- Combining page flipping with the freedom of head rotations supported the reading tasks where frequent jumps occurred between pages.
- While both the reading material and the 3D environment were potential targets of readers' focus, displaying a single

page rather than surrounding the reader with a wall of content added to the feeling of presence and immersion in the reading experience.

6.1 Limitations

We used three different children stories in our study. Different text types are likely to require different interaction possibilities: for example, the reader of a scientific, non-fiction text (such as this paper) will likely navigate back and forth between sections and pages. Such particular behaviour seems to be supported by putting more pages in front of the user at the cost of comfort and a sense of presence as this study showed.

In our study, we did not explicitly measure the feeling of progress and overview, but readers did not always get a complete picture of their current location as pages often occluded each other along the path. A bird-eye view feature could provide readers an explicit option to check their progress, like a mini-map as depicted in Figure 1.

This study solely focused on page-turning techniques whereas its metrics might have also been influenced by the particular display parameters of the reading material. Because we rendered 2D pages from a PDF book, we did not modify the reading experience influencing factors, such font family and page layout. We did, however, make sure that reading materials were all consistent across the study.

6.2 Future Work

Given that we used children's books in our study, we would like to extend our work to other genres. The VR environment could, for example, be chosen based on the underlying mood of the reading material. For textbooks, on the other hand, related 3D materials to support the content's understanding could be present or make an entry at appropriate times. Xu *et al.* [32] investigated the page-turning behaviour of 174 children with printed and e-books identifying particular challenges to navigation that e-books present. With VR having inherently different characteristics, there is a great, unexplored ground for future research on effectively displaying and navigating text in virtual environments.

7 CONCLUSION

Much research has focused on textual interfaces on 2D displays, but little work has been done on the user's reading experience in immersive, 3D virtual environments. VR environments offer new ways of presenting and navigating text, thereby challenging the static life text tends to lead on paper and also 2D screens. To allow readers to step into and effectively flip through virtual books, we devised a 3D reading environment with three page-turning techniques for VR. We conducted a user study with 18 participants to answer the question of what might be effective ways to flip between pages (**RQ1**) and how would these affect the reading experience (**RQ2**). Our study assessed metrics of comfort, sense of presence, and readability. Results showed moving pages towards the user generally supported the reading flow and aspects of immersion. Allowing readers to explore the reading environment freely in 6 DoF, on the other hand, provided more of a feeling of agency but at the cost of reading speed. Reading interfaces in VR have tremendous potential for immersing the reader in a story. While efficient text rendering remains to be an actively researched area in VR, our work presents page-turning techniques as a design element for immersive reading interfaces.

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