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"It Deserves to Be Further Developed": A Study of Mainstream Web Interface Adaptability for People with Low Vision

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To provide accessible but also usable web interfaces to people with low vision (PLV), academics and regulators provide guidelines in the form of adaptation techniques, as well as adaptable interfaces. Following these recommendations, practitioners developed mainstream solutions such as the Microsoft Immersive Reader. With this kind of solution, PLV can adapt or customize web user interfaces in terms of style and structure. This study aims to explore the adaptation carried out by PLV. A mixed methods research design, including both accessibility and usability concerns, allowed us to capture the user interactions, observe them, and access their expressed perception of usability. Findings show the universal nature of mainstream solutions does not support the diversity of PLV. We believe that universal adaptability features better benefit users with less severe and more common visual impairments. Finally, we discuss potential improvements and future work to support a wider range of PLV.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; *Accessibility systems and tools.*

Additional Key Words and Phrases: visual impairment, low vision, accessibility, usability, web, adaptation

1 INTRODUCTION

According to the World Health Organization, 285 million people worldwide are visually impaired, and 86% of them have low vision [35]. Low vision refers to diverse types of visual impairments other than blindness, such as low visual acuity, light, glare or contrast sensitivity, field vision loss, or color vision deficiencies [35]. Thus, the diversity of people with low vision (PLV) requires different needs in terms of access and use of Information and Communication Technology (ICT) [29]. However, with the knowledge that one size does not fit all, adaptation is suitable to cope with diversity in the field of Human-Computer Interaction (HCI) [28]. In fact, regulators such as the W3C extended accessibility guidelines with requirements for PLV [35]. Many requirements concern the capacity of a system to provide an interface presentation that can be adapted by PLV. Moreover, mainstream solutions followed these prescriptions through a universal perspective. In this category belongs the Microsoft Immersive Reader, which enhances the visual reading environment through numerous adaptation capabilities. In this exploratory study, we seek to answer to *how people with low vision benefit from web user interface adaptability?* This research question was motivated by the fact that PLV needs better vision enhancement tools [29], and web interfaces' adaptability is promising when it is designed into the system [27, 35]. Secondly, and to the best of our knowledge, no prior studies investigated web adaptability performed by PLV. Researchers, practitioners, and regulators usually focused on adaptation techniques to be made by web designers [15, 20, 33, 34], while few studies explored the benefits of browser reader views on people with cognitive disabilities [9]. In this research, we captured the user interactions, observed them, and accessed their expressed perception of usability regarding web interfaces adapted with the Microsoft Immersive Reader. We compared this scenario to tailored web interfaces that implement accessibility guidelines (WCAG 2.1) and adaptation techniques suitable to PLV. Our contributions are twofold: 1) a data collection and analysis triangulation through a mixed methods research design, and 2) an exploration of web interfaces adaptability performed by PLV.

2 RELATED WORK

2.1 Web Accessibility and Usability for People with Visual Impairment

Accessibility is defined as *"the extent to which products, systems, services, environments and facilities are able to be used by a population with the widest range of characteristics and capabilities (e.g., physical, cognitive, financial, social and cultural, etc.), to achieve a specified goal in a specified context."* [17]. Regarding ICT related to accessibility research, the web is the most popular technology [10]. Web accessibility means that web contents are designed and developed on the principle that all people with disabilities can use them [34]. The predominant approach for making accessible websites is to apply accessibility guidelines [22], of which the best known come from the W3C through the Web Accessibility Initiative [20]. However, from the beginning of accessibility studies to now, numerous works reported that respecting accessibility regulations alone is not sufficient [19, 32]. Compliance with web accessibility norms does not guarantee that people with visual impairment can reach their goals with a reasonable amount of time and effort [3, 7, 30]. Moreover, accessibility problems can be divided into three types [19]: problems not covered by guidelines, those covered by guidelines that are not implemented within websites, and those covered by guidelines and implemented. To move away from a problem-based approach, *"web accessibility research should take the example from usability research, to define a much broader set of design principles based on user data, and on the use of the web by people with disabilities"* [19]. Following this perspective, usability is the second half of the accessibility story. In that sense, accessibility is a prerequisite for basic use while usability is concerned with optimized use [36]. From another perspective, accessibility and usability problems can be seen as two overlapping sets which could include: *pure accessibility* problems that affect people with performance limitations, *pure usability* problems that affect persons without limitations, and *universal usability* problems that affect every user [18]. Beyond accessibility literature, accessibility can also be seen as a factor of usability [23]. Despite the diverse opinions regarding the relations between accessibility and usability, both need to be considered to develop web interfaces.

2.2 Adaptation to Promote Usability of Web Interfaces to People with Low Vision

The growing availability of digital text in audio or braille format does not prevent the continuing importance of visual reading [29, 37]. PLV can get access to digital texts by increasing the font sizes, which require either large screens or screen magnification technology [20]. Moreover, they combine technical accommodations with physical ones, such as positioning themselves closer to the screen [1]. Although assistive technologies have advanced, PLV need better vision enhancement tools [29]. On the other hand, the PLV population has the particularity to be diverse, which is particularly challenging in HCI [25]. To cope with diversity and to ensure the accessibility and the usability of interactive systems, user interface adaptation seem suitable [27]. Coarsely, approaches to adaptation of interactive systems can be classified into two broad categories, namely user-invoked adaptation (adaptability) and automatic adaptation (adaptivity) [26]. An adaptable system (via adaptability mechanism) offers users the capability to alter the system's characteristics. Users select between different alternative presentation and interaction characteristics, among the ones built into the system. In that sense, adaptation is defined at the design time. On the other hand, adaptivity refers to the ability of the interface to dynamically derive knowledge about the user, the usage context, etc., and to use that knowledge to further modify itself to better suit the revised interaction requirements. An adaptive system automatically alters its characteristics at run time, based on assumptions about the user's current usage.

Specifically for PLV, numerous researchers, practitioners and regulators followed the path of adaptation. Tan et al. [31] designed an approach to develop an adaptive and adaptable system that present accessible graphical web contents for people with visual impairment according to their profiles and preferences. Aiming to improve the accessibility of web interfaces with minimal adverse side effects, Bigham [1] developed a script that performs an automatic magnification. Another line of research is focused on adaptation techniques for the Web [15, 33]. Moreno et al. [15] explored and evaluated techniques and approaches for personalized interfaces for PLV. In a setting including adapted and non-adapted web pages and two assistive technologies (browser zoom and screen magnification), they found that the advantages of some adaptation techniques depend on the type of assistive technology used.

In mainstream web-based systems, adaptability is actually common. Websites intended for PLV provides customizable user interfaces through features like text magnification and color customization[1]. Elsewhere, popular web browsers provide a *reader mode* (e.g., Mozilla Firefox, Safari). Such kind of systems take as input the content of a web page and modifies its structure (e.g., linearized in one column), its presentation (e.g., present it on a narrow page), filters some content (e.g., buttons, ads, background images), provides few styling options (e.g., fonts, colors), and contains a read-aloud feature [9]. Mainstream user agents, which provide some features to assist individuals with disabilities and target broad and diverse audiences [34], are now conveying accessibility in the cloud. As an example, Microsoft developed an Immersive Reader that aims to support students with dyslexia and/or with low vision in reading activities [11, 13]. Also, font size, colors, and contrasts can be easily customized to correspond to PLV needs [13, 14]. This market comprises several solutions following the same line of universal access, such as Helperbird, Snap&Read, Read&Write, and Mercury Reader.

3 USER STUDY

To explore the benefits and pitfalls of web interfaces adaptability carried out by PLV, we adopted a positioning in which accessibility is a necessary precondition for usability [36]. Therefore, we designed two scenarios implying (Figure 1): 1) tailored web interfaces corresponding to an accessibility gold standard, and 2) adaptability features provided by Microsoft's Immersive Reader. PLV accessed both interfaces through a screen magnifier. We selected the Immersive Reader because it provides accessibility support to PLV [13], has solid theoretical and empirical foundations [12], and offers more accessibility options than other reading views of popular browsers [5].

For Scenario 1, all web pages obtained an accessibility level of AA (WCAG 2.1). In addition, we applied a set of adaptation techniques for web interfaces for PLV [15, 20, 33]. For Scenario 2, we integrated the Immersive Reader with the Javascript SDK v1.1.0[2] in a website developed for this study. Five web pages, that are varied in terms of structure, content, and presentation, have been specifically created for this study: a short biography (Text), a glossary of terms (Text Ordered), short explanations with equations (Math), a text with tables about the solar system (Table), an article with images and multiple columns (Complex Layout). We opted for educational web contents because ensuring their accessibility is typically challenging [2], and the Immersive Reader is suitable for this purpose [11].

3.1 Participants

Eight participants with low vision, five men and three women of different age ranges, took part in this study. We focused on people with moderate to severe visual acuity, and/or glare or contrast sensitivity [35]. Participants were recruited by a member of the Swiss Federation of the Blind and Visually Impaired in which all are registered. Participants are Windows users, self-reported no prior experience with the Immersive Reader, and at least five years of experience using

[1]See: https://www.afb.org/
[2]https://github.com/Microsoft/immersive-reader-sdk

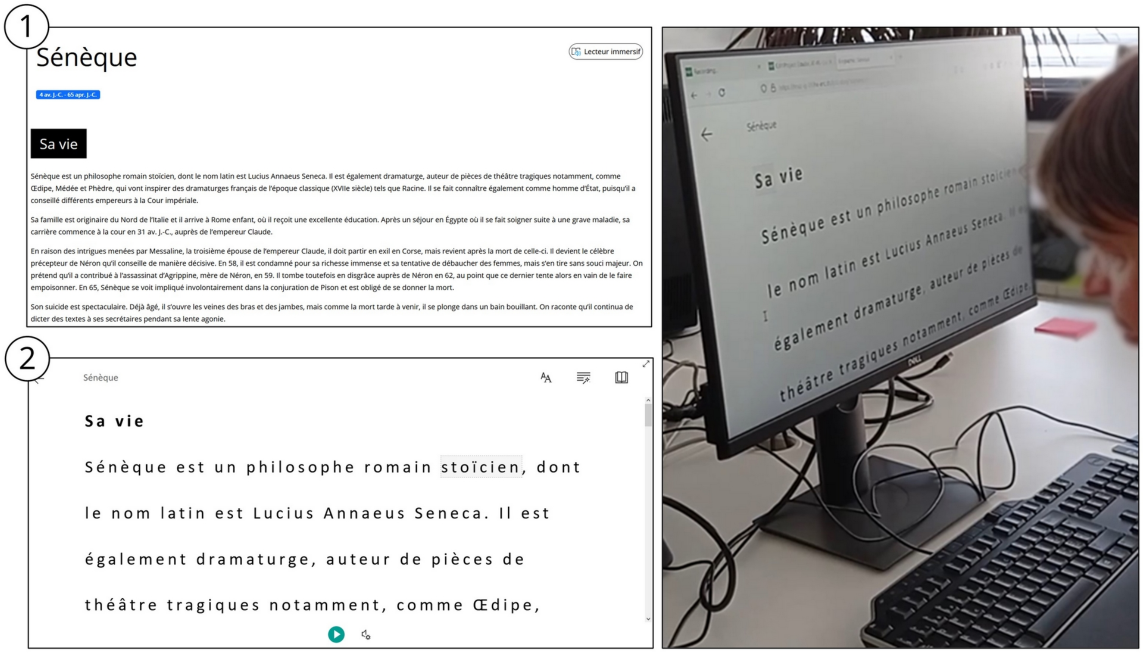


Fig. 1. On top left, a web page corresponding to the Scenario 1. On bottom left, the same page corresponding to the Scenario 2 (Immersive Reader, Microsoft Corporation ©). On the right, a participant (P2) performing an information search task.

Table 1. Participants and Settings. Legend: Vision impairment regarding visual acuity according to the International Classification of Diseases 11. ZoomText Color Sheme: Dark (black background and white text), inverted colors (Inv.). Immersive Reader Color Scheme : Dark (black background and white text), Light Green (light green background and black text), Sepia (sepia background and black text).

Participant ID	P1	P2	P3	P4	P5	P6	P7	P8
Gender	F	M	F	M	M	M	F	M
Age	30-39	40-49	20-29	40-49	50-59	40-49	60-65	30-39
Level of Vision	No	Moderate	Moderate	Severe	Severe	Severe	Moderate	Moderate
Sensitivity	Glare	No	No	Color	Color	No	No	No
Experience (year)	5-7	9+	9+	9+	5-7	9+	7-9	9+
Screen Distance (cm)	40-60	20-40	40-60	<20	<20	40-60	40-60	40-60
ZoomText Settings (Scenario 1 / Scenario 2 only if applicable)								
Magnification Level	x1	x2	x1,6 / x1	x4 / x3,5	x7	x6 / x4	x2	x3
Colors Scheme	Inv. / -	-	-	Inv. / -	Dark / -	-	-	Inv. / -
Mouse Cursor (Yes/No)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Immersive Reader Settings (Scenario 2)								
Font	Calibri	Calibri	Calibri	C. S. MS	Calibri	Calibri	Calibri	C. S. MS
Font Size (px)	42	42	42	42	20	42	42	28
Line Spacing (Yes/No)	Yes	Yes	No	Yes	Yes	No	Yes	No
Colors Scheme	Dark	-	-	Dark	Dark	-	Sepia	Green

a screen magnifier. They use ZoomText as the main assistive technology but are also skilled with other kinds of screen magnifiers.

3.2 Procedure

We invited participants by phone. At this moment, we also collected participant data, including the visual impairment and the needs regarding the interface adaptation. Participants using ZoomText and without prior experience with the Immersive Reader were invited to conduct an experimental session in a laboratory. On arrival, each participant signed a consent form. Then, they participated in a study that included three parts: (1) a formative training, (2) an experiment including information search tasks in two scenarios, and (3) a post experiment interview. The entire session lasted between 1h-1h30 per participant.

Part 1: Formative training. Participants started the study by discovering the adaptability features of the Immersive Reader. Then, they customized the screen magnifier ZoomText and the Immersive Reader with the most suitable parameters to their needs (see Table 1). This part took about 10 minutes per participant.

Part 2: Information search tasks. Then, participants performed five information search tasks within web pages in both scenarios. To complete a task, participants needed to click on a text element on the page. The scenario order was randomized, as well as tasks within scenarios. Also, we counterbalanced scenario order. The time limit for each task was 3 min. The guidance during the experimental session was conducted with the usability evaluation software Loop11 and a researcher present in the lab. Also, sessions were recorded via a screencast and a camera located behind the user.

Part 3: Post experiment interview. Finally, each participant took part in an interview. More specifically, they give us their perception of performance, opinions, and suggestions about web interfaces adaptability with the Immersive Reader. This part took about 20 minutes per participant.

3.3 Data Collection and Analysis

We collected subjective and objective data. About subjective ones, we created an interview guide with open-ended questions based on the perceived usability literature [8]. Regarding objective data, we captured user activities performed at the operating system level with Recording User Input (RUI, v2.3) [6], and at the web interface level with event-based analytics (PostHog). We were particularly interested in cursor movements because there are significant differences in the interaction styles of users with varying visual profiles [4]. To complete these data, we measured participant's performance on four usability metrics: *Task completion time by page* (TCT), *Number of tasks completed* (NTC), *Total scroll performed vertically by page* (Scroll Y), and *Total pixels travelled with cursor by page* (TPT).

Our analysis combines qualitative analysis with descriptive statistics. To support qualitative analyses, we gathered and plotted user log data per task, per user, or per scenario. Regarding observation on video recordings, we performed a two-stepped analysis. In the first step, we documented the interactions performed during each task. We crossed checked our observations with mouse cursor plots. After a second observation round, we obtained a set of browsing strategies. Regarding interviews, we performed a two cycles coding process on complete transcripts [21]. First, we performed deductive coding based on a provisional list of codes grounded on HCI and visual impairment literature. In a second coding step, we grouped codes into themes. These analyzes were facilitated by NVivo, which was particularly helpful in retrieving and reorganizing our coding structure.

4 RESULTS

4.1 Observed Browsing Strategies

The analysis of participant interactions provided five browsing strategies: selective scanning, linear scanning, selective reading, and full listening (see Table 2). In scanning strategies, the mouse cursor allows performing changes in the field

Table 2. Observed Browsing Strategies. Each illustration represent a typical mouse cursor movement corresponding to a strategy. For readability, illustrations respect approximately the aspect ratio 1920x1080.

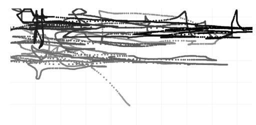
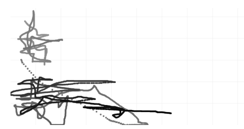
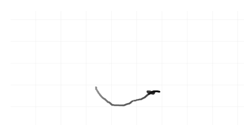
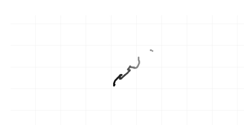
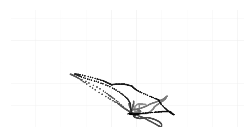
Browsing Strategy	Interaction Pattern	Illustration	Observed in
Linear scanning	Regular mouse move on the X axis, sometimes with saccades, corresponding to the content length. The page content is discovered progressively.		Six participants who magnified the screen (P2-P8).
Selective scanning	Similar to a linear scanning, but only in a part of a page. Often associated with scrolling. Highly dependent to the interface structure and style.		All participants.
Full reading	Read entirely the text with no or little help of the mouse. Scrolling used if needed.		Two participants who need less magnification correction (P1, P3).
Selective reading	Read parts of the text with no or little help of the mouse. Often associated with scrolling. Highly dependent to document structure and style.		Two participants who need less magnification correction (P1, P3).
Full listening	Launch the read-aloud features one or multiple times until finding the information. Click on UI button or the keyboard shortcut.		Three participants with a moderate or severe visual acuity (P4, P6, P7). Only in Scenario 2.

Table 3. Observed Browsing Strategies per Participant and Scenario

Participant ID	P1		P2		P3		P4		P5		P6		P7		P8	
Scenario	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Selective scanning	1	1	0	1	1	0	2	1	4	3	5	1	3	0	2	3
Linear scanning	0	0	4	4	3	0	3	2	1	2	0	0	2	2	2	2
Selective reading	3	3	1	0	1	4	0	0	0	0	0	0	0	0	1	0
Full listening	0	0	0	0	0	0	0	2	0	0	0	4	0	3	0	0
Full reading	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0

of vision, and rhythm the content discovery. Some participants avoided scanning strategies by reading or listening to the text. The majority of participants changed their browsing strategy at least one time when they could adapt the web interface (all excepted P1, see Table 3). Also, three participants used the read-aloud feature of the Immersive Reader (P4, P6, P7). One participant (P3) obtained the greatest benefits of adaptability and could perform a selective reading in place of a selective scanning.

Table 4. Usability Metrics per Participant and per Scenario. NTC denotes *Number of tasks completed*, TCT denotes *Task completion time by page*, Scroll Y denotes *Total scroll performed vertically by page*, and TPT denotes *Total pixels travelled with cursor by page.*

Participant ID	P1		P2		P3		P4		P5		P6		P7		P8	
Scenario	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
NTC	5	5	4	3	4	5	4	4	4	2	5	3	5	2	5	5
TCT (s)	22	40	91	123	72	49	148	116	123	171	42	141	65	172	48	79
TPT (px\\$10^2$)	23	40	127	384	109	23	365	320	203	300	129	245	179	378	208	377
Scroll Y	7	35	26	39	15	13	28	40	20	14	13	20	7	16	15	14

4.2 Perceived Usability of Mainstream Web Interface Adaptability

Impact on User Performance. The narrow page presentation coupled with suitable font settings is mentioned as an advantage for half of the participants (P3, P4, P7, P8), while two of them reported an improved browsing strategy (P3, P8). As stated by P8, *'Everything is there, so it's much easier visually. There is a lot less scanning at eye level.'*, while P3 mentioned having performed a selective reading (skim reading). Others argued that they found the information target more quickly and with fewer efforts because the narrow page presentation allows traveling less distance with the mouse (P3, P4). Two participants emphasized the benefits of the style simplification (P7, P8), while two others explained that the loss of content (e.g., images), structure (e.g., double column), and style (e.g., font color) caused a feeling of being lost (P4, P6). Finally, the three participants that used the auditory modality argued that listening to the text was effortless and helpful (P4, P6, P7).

To complete the *Table task* (in which tables are linearized, Scenario 2), seven participants mentioned the same browsing strategy. As summarized by P3 *'I had to count the Jupiter's position to find the corresponding temperature'*. This strategy was less effective or effortful for six participants. P2 mentioned that *'[…] if you don't remember that Jupiter is the 5th planet, you won't be able to find the correct temperature. […] you expect something that helps you rather than something that makes you work harder.'*. Because the position of elements in the table needs to be memorized, two participants reported a higher cognitive load (P2, P6). Three participants mentioned a greater difficulty to search the information target when the style is simplified or lost (P1, P6, P7, Scenario 2, Text Ordered). P7 stated, *'The text was so uniformized with the Immersive Reader, I had to read the list twice to make sure I hadn't missed the word. Whereas with ZoomText it was written in big letters, so I didn't even have to look too hard […] which was much faster.'*. Moreover, two participants have not noticed the text in bold in Scenario 2 (P1, P2).

Limited Utility of the Immersive Reader. Six participants found that current capabilities do not entirely meet their requirements (P1, P2, P4, P5, P6, P8), while two participants were very satisfied (P3, P7). As limitations, they mentioned the style and/or structure simplification of the UI (P1, P2, P4, P5, P6), and the capabilities less advanced or absent compared to ZoomText (P1, P2, P4, P8). They mostly agree that the Immersive Reader is *only* useful in continuous, unordered, and unstyled texts (P1-P6). More generally, participants categorized the solution as light, encouraging, but not finished, and with a need for additional features (P1, P2, P4, P6, P8). P2 stated, "*I think there are good ideas but it deserves to be further developed. Right now, it is a basic reader.*". Hence, the Immersive Reader is perceived as a complementary assistive technology, which can be used when an advanced screen magnifier is not available (P1, P4, P8).

Must-Have Functionalities. Participants often take ZoomText's capabilities as a reference. The most important limitation concerns style simplification. Participants mentioned that keeping the style of the original document is the bare minimum (P2, P4), while P1 mentioned that *'It would be nice if the reader enlarged everything proportionally. In* *the original document, the title was large, but in the Immersive Reader, the title was at the same size as the text of the paragraph.'*. To better support the diversity of PLV, participants wanted additional color schemes, a larger choice of fonts (P4, P8), as well as advanced listening mode (per word, per line, per paragraph), and personalized shortcuts (P8).

Satisfaction and Learnability of the Immersive Reader. First, all participants appreciated the advances regarding web interfaces adaptability. Also, they mentioned the terms easy to use (P1, P5, P7), going well (P2), intuitive with very simple options (P3), or quite simple (P4, P8). Regarding learnability, all participants confirmed that the Immersive Reader was easy to learn and a sufficient training time. It can be explained by the clarity of the UI (P3) and the limited number of settings (P1, P3, P6).

5 DISCUSSION

Findings showed that participants with moderate to severe visual impairment benefited a little from web interface adaptability through the auditory modality and one participant with the less severe vision impairment highly benefited from the visual enhancement. In line with Szpiro et al. [29], different visual abilities lead to different interactions with technology. However, the universal capabilities of the Immersive Reader did not support the majority of participants and the solution suffered from a comparison with a screen magnifier with more advanced features.

5.1 Improvements for Web Content Reader

Adaptation capabilities provided by the Immersive Reader did not meet the requirements of the wide range of PLV. Thus, there is still a need for better vision enhancement tools [29]. Mainstream web user agents must provide more advanced personalization in terms of all components of a user interface (style, structure, content, and behavior) [16]. For example, they must provide more advanced styling options, support (or better support) a wider range of content (e.g., images, tables), offer more shortcuts, and multiple read-aloud modes. We denote that participants' suggestions are in line with the W3C's requirements for adaptable systems for PLV [35].

5.2 Positioning Web Content Readers

Our results show that web interface adaptability provided by a mainstream web content reader is promising, but struggles to satisfy the diverse PLV needs. While PLV have even more possibilities to move to strategies that imply less effort, not all of them benefited from adaptable web interfaces. Due to overlapping features between a mainstream reader and a screen magnifier with advanced options, most PLV could prefer the latter. Moreover, setting the adaptation within different systems is a difficulty expressed by PLV [29, 33], and adding a customization layer will make the task more tedious. Because the positioning of the Immersive Reader belongs in universal access, PLV with less severe and more common vision impairments seems better benefit from it. Taking these limitations into account, this kind of solution provides an alternative to answer issues about assistive technology and stigma [24], particularly about *newly* PLV who would not want a screen magnifier with advanced options.

5.3 Limitations and Future Work

Our sample size does not allow obtaining representative results or evidence with statistical significance. A larger sample size could allow to better benefit from usability metrics and compare participants by low vision type or severity. As shown by the changes related to user's browsing strategies and screen magnifier customization, we believe that the effect of web interface adaptability on our findings is substantial. However, because the Immersive Reader and ZoomText capabilities sometimes overlap, a mixed effect when adaptation is carried out with both tools could not be prevented. Also, no prior experience with the use of the Immersive Reader could also engender a choice of unsuitable parameters. For these reason, we aim not to conduct a comparative study between both systems, but to explore the benefits and pitfalls of new adaptation possibilities for PLV. Future studies can be set up with greater control of settings that influence the adaptation. Finally, machine learning could be used to learn from interaction patterns and infer PLV needs in terms of suitable adaptation parameters.

6 CONCLUSION

In this paper, we explored the benefit and pitfalls of web interfaces adaptability performed by PLV when using a mainstream solution (the Microsoft Immersive Reader) in comparison to an accessibility gold standard. To do so, we conducted a mixed methods research design through an objective and subjective data collection and analysis triangulation. Findings show that current adaptability features cannot support the diversity of PLV needs. With some improvements of mainstream readers, we believe that web interfaces adaptability could be a solution to address accessibility issues to larger sub-populations of PLV.

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