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Exploring Low Vision Simulations in Participatory User Testing

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Résumé

Le web reste, encore aujourd'hui, largement inaccessible aux personnes en situation de handicap, et en particulier aux personnes malvoyantes. Une des méthodes utilisées pour promouvoir l'accessibilité des applications mobiles et des sites web est par la simulation de handicap par des personnes sans handicap. Toutefois, cette approche est critiquée aussi bien par les personnes en situation de handicap que par les experts quand l'approche est utilisée par les développeurs et designers et non dans un cadre de recherche en expérience utilisateur (UX). Ainsi, l'étendue de l'efficacité des tests utilisateurs par simulation de handicap visuel reste encore incertaine. Dans ce mémoire, différentes simulations immersives sont comparées à travers les avantages et inconvénients qu'elles présentent pour les tests utilisateur impliquant des mesures neurophysiologiques. Ensuite, dans quelle mesure le comportement visuel des participants portant une simulation de handicap visuel (*Cambridge Simulation Glasses*) pourrait reproduire celui des participants malvoyants lors d'une tâche de recherche visuelle est exploré avec des mesures oculométriques. Les résultats montrent que les lunettes analogues et la réalité augmentée sont deux catégories prometteuses pour la recherche UX. Cependant, les lunettes analogues demeurent une alternative plus simple et qui peut être intégrée aux tests utilisateurs de manière efficace et valide. Les résultats montrent que la simulation reproduit la sensibilité au contraste, le temps de réaction et le ratio de fixations sur les saccades des participants malvoyants, en particulier avec des stimuli à contraste faible. Nous concluons que la reproduction des comportements visuels typiques de malvoyants dans les tests utilisateurs avec des mesures oculométriques est faisable et valide. Ce mémoire contribue à la recherche sur l'accessibilité en identifiant des avenues potentielles pour y intégrer les simulations.

Mots-clés : accessibilité, handicap visuel, malvoyant, simulation d'handicap, expérience utilisateur, mesures neurophysiologiques, oculométrie, recherche visuelle.

Méthodes de recherche : En deux phases, ce mémoire vise à déterminer la mesure dans laquelle les simulations de handicap visuel peuvent être utilisées dans la recherche UX, et plus spécifiquement dans les tests d'utilisabilité participatifs. Tout d'abord, dans une revue narrative de la littérature, deux types différents de simulations immersives sont discutés (lunettes analogues et réalité augmentée) ainsi que leur compatibilité avec les méthodes couramment utilisées dans la recherche UX, notamment les mesures neurophysiologiques. Au total, six lunettes analogues et trois appareils de réalité augmentée sont comparés en fonction de leurs avantages et inconvénients dans les tests utilisateurs. Cette revue vise à identifier un outil de simulation spécifique adapté aux tests d'utilisabilité participatifs, à travers son utilisation dans la littérature et des résultats empiriques. Ensuite, dans une expérience en laboratoire, une simulation de handicap (*Cambridge Simulation Glasses*) simulant un handicap visuel léger à modéré est utilisée dans une étude expérimentale. Au total, neuf participants atteints d'une vision faible à modérée, 12 participants à vue normale et 25 participants à vue normale avec une simulation de vision faible à modérée ont réalisé des tâches visuelles, lesquelles ont été mesurées à l'aide d'un oculomètre. Les mesures utilisées pour comparer l'effet de la simulation sont : le seuil de sensibilité au contraste, le temps de réaction et le ratio de fixations sur les saccades. Notre but est de déterminer si nous pouvons reproduire les comportements visuels des participants malvoyants avec des stimuli à contraste élevé et faible dans une tâche de recherche visuelle.

Abstract

The web today still largely cannot be used by people with disability (PWD), and specifically by people with low vision. One way to promote web and mobile applications' accessibility has been through the use of disability simulations used by able-body individuals. Their use by developers and designers has been criticized by PWD and experts. However, the criticism have not targeted their use in User experience (UX) research. The extent to which low vision simulations can be effectively used in participatory user testing with able-body participants remains unclear. In this thesis, various kinds of immersive see-through simulations are compared according to the advantages and disadvantages they have for user testing involving neurophysiological measures. Then, the extent to which the visual behavior of participants wearing a low vision simulation (Cambridge Simulation Glasses) could replicate the ones of low vision participants in a visual search task is explored with eye tracking measures. Findings show that analog spectacles and augmented reality are two categories promising for UX research. However, analog spectacles, compared to augmented reality, present a simpler alternative that can be integrated into user tests effectively and with validity. Through a between-subject design, results show that the simulation replicates the contrast sensitivity, reaction time and ratio of fixations over saccades of low vision participants, especially with low-contrast stimuli. We conclude that replicating low vision visual behaviors in a participatory user testing with the use of neurophysiological measures is feasible and valid. This thesis contributes to accessibility research by identifying potential avenues to integrate disability simulations in user tests.

Keywords: accessibility, visual impairment, low vision, disability simulation, user experience, neurophysiological measures, eye tracking, visual search

Research methods: This thesis aims at investigating the extent to which low vision simulations can be used in UX research and specifically in participatory user testing. It does so through two phases. First, in a narrative literature review, two different types of see-through immersive low vision simulation are discussed (i.e., analog spectacles and augmented reality head-mounted displays) as well as their compatibility with commonly used methods in UX research, notably neurophysiological measures. Overall, six analog spectacles and three augmented reality devices are compared according to their advantages and disadvantages in user testing This review aims at identifying a specific simulation tool that is suitable for participatory user testing through its use in the literature and empirical findings. Second, in a laboratory experiment, one disability simulation (i.e., Cambridge Simulation Glasses) simulating mild to moderate low vision is used in a between-subject design. In total, nine participants with mild to moderate low vision, 12 normally sighted participants, and 25 normally sighted participants experiencing simulated mild to moderate visual impairments performed visual tasks measured through eye tracking in a visual search task. The metrics used to compare the effect of the simulation are: the contrast sensitivity threshold, the reaction time and the ratio of fixations over saccades. We aim to determine whether we can replicate the visual behavior of low vision participants with high and low-contrast stimuli in a visual search task.

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Foreword

This work has been completed as part of the student's Master of Science in User Exeprience at HEC Montreal. The thesis has been approved by the administrative management of the M.Sc. program. Further authorization was given to write this thesis in the form of articles by the program director. The inclusion of each article within this thesis has been approved by all co-authors. The first article, chapter 2, was written in preparation to be submitted to the journal *AIS Transactions on Human-Computer Interaction*. Additionally, a preliminary version of the second article, chapter 3, has been approved to be presented at the *2023 NeuroIS Retreat* in Vienna between May 30th and June 1st of 2023.

The research project included in this thesis has been approved by the Research Ethics Board of HEC Montreal in May 2022 under project number 2023-5025. Accordingly, the research project involving humans as participants was completed ethically.

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I am grateful to my supervisors, Dr. Pierre-Majorique Léger and Dr. Sylvain Sénécal, for creating an enriching environment that has motivated me to push myself to new limits and learn through new experiences every day. The enriching environment they have provided me went beyond my expectations and is more than I could have hoped for.

Last but not least, I am also thankful for the research team and students at Tech3Lab who have assisted me and with whom I have learned so much. Without their continuous efforts and help, this thesis project would not have been possible. I am lucky to have worked with such dedicated researchers. Specifically, thank you to Félix, who showed me the ropes, helped me challenge myself and played an integral part in the success of this thesis. And thank you to Laurène for our friendship and her day-to-day support.

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List of Abbreviations

AR: Augmented Reality

CS: Contrast sensitivity

ECG: Electrocardiogram

EDA: Electrodermal activity

EEG: Electrocephalography

HCI: Human-Computer Interaction

HMD: Head-Mounted Display

ICT: Information and communication technology

PWD: People with disability

UI: User interface

UX: User experience

WCAG: Web Content Accessibility Guidelines

VA: Visual acuity

VI: Visual Impairments

VF: Visual field

Chapter 1
Introduction

The accessibility of information and communication technologies (ICTs) for people with disabilities (PWD) has gained attention in recent years (Mack et al., 2021). As our reliance on ICTs continues to grow and becomes essential to our day-to-day interactions (Babu, Singh, & Ganesh, 2010), there has been continuous implementation of laws and policies from governmental agencies, international organizations, and advocacy groups (Lazar, 2019). This has become more relevant as several essential activities were moved online due to the COVID-19 pandemic (Lai & Widmar, 2021). Regardless, the inaccessibility of web content is still present and has created barriers for PWD and notably for people with low vision. People with mild to severe vision loss tend to be excluded from the digital world as ICTs primarily rely on visual information (Aizpurua et al., 2016; Dobransky & Hargittai, 2016). Globally, there are 285 million people with low visual impairments (VIs), which most often affect people of older age (WHO, 2017; Low Vision, 2023). Considering the world population is aging, these numbers will continue to grow (Macnamara et al., 2021; Zhang & Codinhoto, 2020).

Research in Human-Computer Interaction (HCI) and more specifically User Experience (UX) has focused their attention on the ways the accessibility of web content can be promoted for people with low vision (Mack et al., 2021). However, accessibility research faces the challenge of finding PWD to recruit (Giroux et al., 2021; Kumar, Shree, & Biswas, 2021; Mack et al., 2021). In fact, there is a wide heterogeneity of symptoms which increases the specificity of their disability. To illustrate, two people with the same visual diagnosis could have different visual abilities (Jones, Somoskeöy, Chow-Wing-Bom & Crabb, 2020). Furthermore, this population tends to suffer from comorbid disorders, more than those without VIs. This makes interactive testing increasingly tiring (Macnamara et al., 2021), especially for the aging population (McLean et al., 2014).

Alternative methods for the usability evaluation of web content such as accessibility guidelines, automatic evaluation software and expert opinion have not shown to be effective either (Manca, Palumbo, Paternò and Santoro, 2022). Accessibility guidelines have been described as confusing and difficult to conform to (Abuaddous, Jali, Basir; 2016; Choo, Balan, and Lee, 2019; Clegg-Vinell, Bailey, Gkatzidou; 2014; Tigwell, 2021). Even the best guidelines that are available to us do not represent an exhaustive list of the usability issues that users could encounter when browsing (Aizpurua et al., 2016). Furthermore, automatic evaluation software produces outputs that are difficult to understand (Abuaddous et al., 2016; Kumar, Shree DV & Biswas, 2021) and that can wrongly identify accessibility issues (Choo et al., 2019). Finally, expert opinions can be biased, tedious, and expensive (Kumar et al., 2021). They have reported not knowing how to implement those guidelines and accessibility features (Crabb et al., 2019). Overall, there tends to be a mismatch between the users with disabilites' needs and the recommendations that are produced (Choo et al., 2019).

Consequently, one method that has been used to assess the accessibility of ICTs, is through simulating a disability whereby people without any disabilities experience capability loss through a tool or a device that replicates one or a combination of the symptoms of this impairment (Giroux et al., 2021; Mack et al., 2021). This offers a controlled environment, and a simpler and cheaper alternative that designers and developers of web content have used (Bradley & Domingo, 2020; Tigwell, 2021). It has been reported to help assess accessibility and identify usability issues by allowing for a 'first-person approach' (Choo et al., 2019; Tigwell, 2021; Mack et al., 2021). However, simulating a disability has faced criticism, especially from disability scholars (Hofmann et al., 2020) and from PWD (Tigwell, 2021) mainly for two reasons. First, this method has excluded PWD from the development and design process (Hofmann et al., 2020), and reduces the opportunity to work collaboratively (Tigwell, 2021). Second, the simulation of a disability does not exactly replicate the actual living conditions of PWD and does not consider the acquired abilities they have developed due to their disability (Jones & Ometto, 2018; Macnamara et al., 2021). However, the criticism has targeted the use of simulations by designers and developers and not by able-body participants in the context of user testing.

During participatory user testing, UX research involves measuring both the objective and subjective experiences of the participants. Although subjective measures provide information about the explicit experience of the participant, objective measures tend to be favored as they are more reliable and give insight into the implicit experience (Maia & Furtado, 2016; Riedl & Léger, 2016; Zaki & Islam, 2021). Objective measures are often used in user testing (Zaki et al., 2021). They consist of neurophysiological measures that give information about the attentional, emotional, behavioral and cognitive responses of the participant in response to a stimulus (e.g., web content). Through the use of neurophysiological measures with low vision simulations, a new opportunity for research emerges. The extent to which low vision simulations can replicate the visual ability and behavior of people with low vision in the context of participatory user testing remains unexplored.

1.1 Research Questions

The current thesis examines whether implicit measures such as perceptions and behavior of low vision people can be replicated through the use of low vision simulations. It does so through the investigation of two separate research questions:

1. What are the benefits and limitations of visual disability simulation to measure user experience in participatory user testing of a digital interface in accessibility research?
2. To what extent does the visual search behavior of normally sighted participants experiencing a visual disability simulation can replicate the visual search behavior of people with low vision?

Given the difficulties in the current methods of evaluating the accessibility of web content and the promising use of low vision simulations, it is important to address these questions to determine the extent to which able-body participants experiencing a low vision simulation in the context of user testing is feasible.

A narrative literature review, in preparation to be submitted for the journal *AIS Transactions on Human-Computer Interaction*, is focused on answering the first question. It uncovers various types of simulation tools and devices that have been developed and researched through empirical methods. This review aims at addressing the ways immersive see-through low vision simulation can be used with neurophysiological measures used in UX. The simulations are separated into two categories: Analog spectacle simulations and Augmented reality (AR) using head-mounted displays (HMDs). In this thesis, these two categories are presented according to their advantages and disadvantages in the context of participatory user research. Their compatibility with neurophysiological measures commonly used in UX research, specifically the electroencephalogram (EEG), emotion detection and eye tracking, is then addressed. Through the findings of the literature review, the use of simulations has been shown to be effective in other fields and argues that their use could effectively be extended to participatory user testing. Furthermore, due to the current limits of some neurophysiological measures, their compatibility with the selected simulations would require to be tested to determine the feasibility of measuring the UX of able-body participants experiencing a low vision simulation.

Subsequently, the second research question addresses the way the findings of the first research question can be implemented. Presented in the form of an article, this work is going to be presented between May 30th to June 1st at the *2023 NeuroIS Retreat* in Vienna. To do this, a between-subject experimental design in a lab setting using three groups of participants is conducted. These groups are normally sighted participants, normally sighted participants undergoing a low vision simulation, and low vision participants. The simulation used for the simulation group is the Cambridge Simulation Glasses. Furthermore, their UX is measured through eye tracking. The effect of the simulation on vision is validated through visual tasks conducted on all three groups. First, to quantify the effect of the simulation on visual ability, their contrast sensitivity threshold is measured using the FrACT (Bach, 2006). Second, they all perform a search visual task using high and low contrast stimuli or on a computer screen to determine the effect of the simulation on the visual search behavior. By using eye tracking, the findings show that the disability simulation tends to reduce visual ability and replicate the visual search behavior observed in individuals with low vision.

1.2 Goal and Expected Contribution

The goal of this thesis is to determine the extent to which low vision simulation can be used in UX research to promote the accessibility of digital products delivered to end-users. From this, theoretical, methodological, and practical contributions are expected.

The theoretical contributions relate to the inclusion of disability studies in accessibility research. ‘Disability studies' refers to the discourse centered around understanding disability and advocating against the ableism of PWDs. This thesis is expected to show how simulations help to gain insights into the experiences of PWD. The goal is not to replace PWD, but to inform HCI research on the ways that collaboration can be honored and made more productive.

The methodological contributions involve the experimental design. The inclusion of PWD and simulated disabilities require adjustments in the way a laboratory experiment is conducted to ensure that all participants can have the same experience and avoid unnecessary fatigue. Furthermore, determining the extent to which eye tracking produces valid data also contributes. The aim is to provide guidelines on how to conduct participatory research in accessibility appropriately.

The practical contributions of researching low vision simulation implicate organizations. The simulations discussed in this thesis have been selected according to their availability. In other words, only off-the-shelf simulations that are available for commercial use are discussed and not simulations that require to be validated, that are still in development or in prototyping stages. Therefore, this can offer concrete solutions for UX researchers who want to evaluate the accessibility of web content of ICTs.

1.3 Related Works

This section provides an overview of relevant research related to the field of accessibility that is essential to consider in any investigation of this topic. Specifically, the definition of 'low vision' and its impact on the individual is briefly explained. Second, a key distinction between disability studies and accessibility research is highlighted. Subsequently, the Digital Disability Divide is described, and the barriers experienced by PWD in accessing ICTs are highlighted. Finally, the legal context of accessibility and how policies have contributed to promoting web accessibility are discussed.

1.3.1 Low Vision

According to the National Eye Institute (NEI), 'low vision' is defined as a permanent vision condition that cannot be cured with prescription glasses, contact lenses, medication, or surgery, which makes daily tasks and activities challenging (Low Vision, 2023). Additionally, low vision tends to be degenerative and is particularly prevalent among older individuals (Low Vision, 2023). The most common causes of low vision are age-related macular degeneration, cataracts, diabetic retinopathy, and glaucoma, with symptoms ranging from mild to severe. Some common ones are reduced visual acuity (VA) and contrast sensitivity (CS) such as blurry or hazy vision, central and peripheral vision loss, and night blindness (Bittner et al., 2020; Low Vision, 2023; Jones et al., 2018). Additionally, as of 2017, there were close to five million older adults (i.e., 45 years old and above) in the U.S. with low vision and blindness, which made it difficult for them to access ICTs. This number is predicted to nearly double by 2050 (Varma et al., 2016; Chan, Friedman, Bradley & Massof, 2018). In terms of access to ICTs, evidence suggests that among PWD, the ones with low vision tend to be the most affected by the inaccessibility of web content when compared to other disabilities (Dobransky & Hargittai, 2006; Johansson, Gulliksen & Gustavsson, 2021).

1.3.2 Digital Disability Divide

In the field of HCI, the Digital Divide phenomenon refers to the unequal distribution of access to ICTs and online information, caused by three factors: socioeconomic, governmental, and accessibility (Pick & Azari, 2008). While accessibility is recognized as one of the three central factors of the phenomenon, it has often been overlooked in the literature (Dobransky et al., 2016). The International Organization for Standardization (ISO) defines accessibility as “the extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals in identified contexts of use” (International Organization for Standardization [ISO], 2021). When researching the persistent disparities in digital access, the focus has mostly been on the barriers due to gender, income and geographical location (Adam & Kreps, 2006; Johansson et al., 2021). Due to the lack of attention to ‘accessibility’ in the Digital Divide, HCI and sociology research has focused its attention to look more specifically at the Digital Disability Divide. According to the scholars in the field, many of the barriers affecting PWD to engage in online activities as much as people without is the inaccessibility of ICTs (hardware and/or software) rather than internet skill and sociodemographic factors (Dobransky et al., 2016). The unequal access to the digital world has become increasingly strenuous than in previous decades due to our reliance on it (Dobransky et al., 2016; Johansson et al., 2021).

1.3.3 Policies towards Accessibility of Web Content

In June 2019, the Accessible Canada Act (ACA, 2019) was passed to protect against any discrimination, especially on the basis of disability. In combination with the Accessible Canada Regulations (ACR, 2021), this act is meant to prevent potential barriers that can interfere with users with a disability to use ICTs with ease. Any web content in Canada has to follow the Web Content Accessibility Guidelines’ (WCAG) newest version (currently 2.2) or monetary penalties could be applied (ACA, 2019, p. 50). Across different countries, similar policies have been established against digital inequality. For instance, in the United States, there is the Americans with Disabilities Act and the 21st Century Communications and Video Accessibility Act of 2010. There are similar examples in other countries such as in Australia with the Disability

Discrimination Act (1992), in the United Kingdom (UK) with the Equality Act (2010) and in the European Union with the Web Accessibility Directive as part of the 'Digital Agenda for Europe' (2010; w3.org/WAI/policies/). Together, they promote web accessibility of websites and mobile applications in order to protect any PWD against discrimination to reduce inequalities (Tigwell, 2021; w3.org/WAI/policies/). Furthermore, in 2006 the United Nations adopted the Rights of Persons with Disabilities (CRPD) which includes the importance of equal access to online information for PWDs (Stein, Stein, Weiss, & Lang, 2007; Yusril, 2020).

Additionally, international standards and guidelines, such as the WCAG, have been advocating for a more inclusive web as well. The WCAG, developed by the Web Accessibility Initiative (WAI) established by the World Wide Web Consortium (W3C; Babu et al., 2010; Loiacono et al., 2013; Yusril, 2020), is widely regarded as the "gold standard" in accessibility guidelines (Tigwell, 2021). The goal of the WCAG is to improve user experience by promoting accessibility and providing testable guidelines according to four principles (i.e., Perceivable, Understandable, Adaptable, Robust) for developers and designers of website and mobile applications (Loiacono et al., 2013; WCAG). Furthermore, the newer version (3.0), still in development, is expected to include additional categories (i.e., Testing, Scoring and Conformance) to support developers, designers and policy makers in their decisions to create accessible content.

The ongoing implementation of policies seems to be the biggest contributing factor to the increasing accessibility of ICTs (Lazar, 2021) and has been found to make it more likely that a website will be accessible (Loiacono et al., 2013). Despite legal efforts, the contribution of various advocacy groups as well as international institutions, inaccessibility remains (Loiacono et al., 2013; Scholz, 2017; Tigwell, 2021; *The WebAIM Million*, 2022; Yan & Ramachandran, 2019) and it has been the case for the last 20 years (Takagi et al., 2003). For instance, WebAIM's 2022 annual report has evaluated 1 million home pages of various websites and found only a 1.1% decrease in errors found conforming to WCAG A/AA levels when compared to 2021. Overall, 96.8% of home pages had WCAG failures. In other words, about 3% of the web is accessible. Considering that not all types of features could be assessed automatically, the amount of failures to conform is certainly higher (*The WebAIM Million*, 2022).

1.4 Article 1

The first article is in preparation to be submitted to the journal *AIS Transactions on Human-Computer Interaction*. It is co-authored by Félix Giroux, Sylvain Sénécal and Pierre-Majorique Léger. This article is a narrative literature review that discusses the benefits and limitations of using low vision simulations in participatory user testing with able-body participants. This article serves as a basis for the second article where one low vision simulation and one neurophysiological measure are tested.

Summary

The use of low vision simulations in accessibility research is a controversial topic. On one hand, it has been shown to be useful for designers and developers of ICTs to evaluate the accessibility of web content. On the other hand, it has faced criticism for not including PWD in the process. This literature review shows that their use for participatory user testing can be beneficial to promote accessibility research without the exclusion of PWD.

This literature review explores the extent to which low vision simulations can be used for participatory user testing. It does so in two ways. First, the current literature on low vision simulation is explored. Various fields of expertise, including HCI, have used low vision simulations in empirical research to determine the effect low vision has on performance such as walking, driving, cognitive ability, daily tasks, sports, and more. Second, the compatibility with neurophysiological measures is discussed, notably measures that require access to the head and face (i.e., EEG, emotion detection and eye tracking).

Through the findings, it is revealed that low vision simulations are effective in replicating the perceptions and behaviors of PWD making it possible to extend their use on participants in a user testing setting, but whether neurophysiological measures can be recorded while participants are experiencing the simulation has yet to be tested. Overall, this review suggests that this accessibility research in UX through user testing with simulations can be an effective tool to gather useful accessibility recommendations.

1.5 Article 2

The second article has been accepted to the *2023 NeuroIS Retreat* in Vienna and is going to be presented between May 30th to June 1st. This article has been co-authored by Félix Giroux, Camille Lasbareilles, Jared Boasen, Sylvain Sénécal and Pierre-Majorique Léger. This article builds upon the findings of the first article where a low vision simulation (i.e., Cambridge Simulation Glasses) is tested with an eye tracker (i.e., Tobii Pro Nano) through a pilot study. The Cambridge Simulation Glasses were selected because they can be easily integrated into a user test, their severity can be adjusted and there are readily available. This decision was made with the help of the industrial partner involved in this UX research project. Furthermore, the version of the article in this thesis includes more information than the submitted version for the conference. This version goes more in-depth into the process of recruiting the participants, the experimental design and the hypothesis building.

Summary

The literature review article helped to determine that the use of low vision simulations can be extended to participatory user testing. However, it noted that the compatibility with neurophysiological measures still needs to be tested to determine the extent to which it produces valid data. This article tests one low vision simulation with one neurophysiological measure.

This article is a pilot study that investigates whether the visual search behavior of low vision people on a computer interface can be replicated with normally sighted participants experiencing a visual disability simulation. Using a between-subject design, 47 participants performed computer-based vision tests to assess their CS threshold and a visual search task with high and low contrast stimuli. In total, nine low vision participants, and 38 normally sighted participants with and without visual disability simulation glasses participated. With the use of eye tracking, it was found that the visual disability simulation tends to replicate the visual search behavior of low vision participants. Following the results of this article, future works (not included in this thesis) will test the same experimental design in an ecological task (i.e., a banking platform) to determine whether similar results can be found in a real-world example.

1.6 Thesis Structure

This thesis is structured in four chapters. The first chapter introduces the current context of accessibility research and the key elements of the thesis: research questions, goals and expected contributions. A related works section is added to provide additional information to grasp the full extent of the context this thesis lies in.

The two following chapters are in the form of articles, each written for a journal and conference publication respectively.

The first article consists of a narrative literature review. It focuses on gathering an understanding of the current literature and body of knowledge around the use of low vision simulation for participatory user testing. Furthermore, it focuses on addressing their compatibility with neurophysiological measures used in UX research. This article aims at understanding what is known about the possibility of measuring the UX of normally sighted participants experiencing a low vision simulation.

The second article describes a laboratory experiment where a low vision simulation was used and tested on normally sighted participants. Additionally, UX was measured through an eye tracker. The goal is to determine whether the visual ability and behaviors that are measured with an eye tracker can replicate the ones of people with actual low vision.

The fourth and final chapter concludes the thesis by reiterating the key findings from both articles and by discussing their theoretical, methodological, and practical implications. The thesis ends with a discussion that goes over the limits of this research and future research opportunities.

As a last note, a global reference list can be found at the end of the final chapter and both articles each have their respective reference list.

1.7 Personal Responsibilities and Contributions

The following table details the personal contribution of the student. It summarizes the important steps taken for the process of completing this master's thesis at the Tech3Lab. Each step of the process is accompanied by the different tasks involved and the contribution is quantified in percentages. These percentages do not take into account the support and input of the co-directors during this project. This research project is also partly involved in a doctoral thesis. The contribution of the doctoral candidate involved is also not taken into account.

Table 1: Contributions related to the research project and writing the articles.

Steps in the process	Contribution
Research question	Identifying gaps in current literature and defined the research problem and its implications – **100%** Defined the research problem – **100%** - Defined research questions - Identified the constructs to be tested
Literature Review	Conducting relevant research, reading scientific articles related to the topic – **100%**
Conception and experimental design	Designing and development of the experimental protocol – **100%** Determining the operational stimuli – **60%** - Searched the literature and identified relevant visual search tasks - The remaining 40% belongs to the research team Applying to the CER – **100%** - Prepared the documentation related to the submission of the application to the CER
Recruitment of participants	Recruiting the participants for the studies – **30%** - Creation of the recruitment tool for the participants - Determining the inclusion and exclusion criteria for the two groups of participants - The remaining 70% belongs to the research team
Pre-tests and data collection	Pre-testing the experimental design and collecting data – **100%** - Take charge of the data collection - In collaboration with the research team and co-authors
Data analysis	Extracting the eye tracking data – **90%**

	- The remaining 10% belongs to the research team Analysis of the eye tracking data – **90%** - The remaining 10% belongs to the research team and the Tech3Lab's statistician
Writing the thesis	Writing the thesis – **100%** Writing the first article – **100%** Writing of the second article – **90%** - The remaining 10% belongs to the co-authors

Chapter 2
A Narrative Literature Review of Immersive Low Vision Simulations for Participatory User Testing with Neurophysiological Measures*

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Abstract: In Human-Computer Interaction (HCI) research, the use of disability simulation has been used as a way to adopt a first-person approach for usability evaluations. While many developers and designers rely on simulating an impairment, notably low vision, to assess the accessibility of their interfaces, the use of simulations in the context of a user test has yet to be explored. This article is a narrative literature review providing an overview of the different types of low vision simulations available to be used for user testing and their compatibility with neurophysiological measures. In this review, articles on simulations, are included when they meet the following criteria: (1) immersive, (2) off-the-shelf, and (3) real-world environment. The review also includes articles on commonly used neurophysiological measures in UX research such as EEG, emotion detection and eye tracking. The findings revealed that low vision simulations are effective in replicating the visual ability and behaviors of PWD, making it possible to extend their use on participants in a user testing setting, but whether neurophysiological measures can be recorded while participants are experiencing the simulation has yet to be tested. Overall, this review suggests that this accessibility research in UX through user testing with simulations can be an effective tool to gather useful accessibility recommendations.

Keywords: Accessibility, Usability, User Experience, UX, HCI, Literature review

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2.1 Introduction

Accessibility research has increased in popularity in recent years. Gradual attention to promoting accessibility to Information and Communication Technologies (ICTs) has mainly been centered around people with low vision conditions (Mack et al., 2021) as the use of ICTs such as mobile and desktops primarily rely on visual information (Aizpurua, Harper, Vigo, 2016). Conducting such research is important because low vision tends to be one of the conditions the most affected by inaccessible web content (Adam & Kreps, 2006). In fact, according to WebAIM's 2022 annual report, it was found that only about 3% of the web is accessible. Moreover, as we live in the information age, ICTs become an essential part of our interactions, not only social but also institutional (i.e., education, work, and commerce; Babu, Singh, & Ganesh, 2010, p. 74) which has become more relevant as several essential activities were moved online due to the COVID-19 pandemic (Lai & Widmar, 2021). Furthermore, as of 2017, there were close to five million older adults (i.e., 45 years old and above) in the U.S. with low vision and blindness, which made it difficult for them to access ICTs. This number is predicted to nearly double by 2050 (Varma et al., 2016; Chan et al., 2018).

The promotion of ICT accessibility can be done by participatory user testing through evaluating web content in UX research. Participatory research requires the involvement of participants with or without disabilities. While both require consideration, the participation of PWD faces more challenges: recruitment and disability factors. First, finding PWD to recruit is difficult (Kumar et al., 2021; Mack et al., 2021; Sears et al., 2011). Second, people with low vision also tend to suffer from comorbid disorders more than those with normal vision (McLean et al., 2014) which makes interactive testing increasingly tiring (Macnamara et al., 2021), especially for the aging population (McLean et al., 2014). Moreover, participatory experimental design with PWDs tends to require additional resources (e.g., time, money, and training; Ates, Fiannaca & Folmer, 2015; Bradley & Domingo, 2020; Pernice & Nielsen, 2001; Tigwell, 2021). Therefore, as a solution to these challenges, the simulation of disabilities on able-body individuals has been used in accessibility research and as a way to support UX researchers during user testing (Ates et al., 2015; Giroux et al., 2021; Keates and Looms, 2014; Macnamara et al., 2021; Tigwell, 2021). Research with simulation of disabilities is conducted with participants with normal vision who use tools that simulate low vision by replicating a specific visual condition for the duration of the usability evaluation (Juniat et al., 2019; Zallio, Waller, Chivaran & Clarkson, 2021). This offers a controlled environment, and a simpler and cheaper alternative that has most often been used in research to generate empathy and for educational purposes (Bradley et al., 2020; Hollo, Brigandi, Jelsema & Shi, 2021; Maher & Haegele, 2022; Silverman, 2015; Tigwell, 2021).

Although the literature suggests that visual disability simulation can be useful to identify usability issues and design recommendations with ICT prior to testing them with users with disabilities (Choo, Balan & Lee 2019; Giroux et al., 2021; Goodman-Deane, Waller, Collins & Clarkson, 2013), some studies have criticized this practice (Ates et al., 2015; Jones et al., 2018; Tigwell, 2021). The critics specifically target the use of the simulation by designers and developers for the ableism of PWD (Tigwell, 2021) and not by users during participatory user testing in the context of UX research.

The current literature addressing the use of low vision simulation for participatory user testing is scarce. There are no literature reviews discussing how low vision simulations can be used in UX research to promote web accessibility. Understanding the benefits and limitations of using different simulation methods for low vision to promote the accessibility of web content needs to be investigated. This article examines the potential application of low vision simulations in accelerating the research in accessibility, facilitating user testing, and promoting inclusive design through a narrative literature review. To achieve this, the following research question is addressed: *What are the benefits and limitations of visual disability simulation to measure user experience in participatory user testing of a digital interface in accessibility research?* This research question is focused on exploring the extent to which the user experience of able-body participants undergoing a low vision simulation can be measured in user testing.

In this literature review, two categories of simulations are discussed: analog simulation spectacles and augmented reality (AR) head-mounted displays (HMDs). These tools that have been developed and tested will be explored by taking several dimensions into consideration: the level of immersiveness, the way the symptoms are represented, the ease of use of the device, the way it can be validated and their compatibility with UX neurophysiological measures. Each type of simulation is described first, and then its benefits and limitations are discussed.

The findings suggest that the use of low vision simulation can be extended to participatory user testing, as other fields have shown their use to be positive and effective. Additionally, the findings highlight the need for testing the feasibility of measuring the UX of participants undergoing a low vision simulation with neurophysiological measures. These promising findings are expected to contribute to the advancement of accessibility research.

2.2 Theoretical Background

The key concepts relevant to this literature review study are disability studies and accessibility research, as well as neurophysiological measures, which are described in the following sections.

2.2.1 Disability Studies Vs. Accessibility Research

One distinction that is important to be addressed is the difference between disability studies and accessibility research (Mack et al., 2021). 'Disability studies' refers to the discourse centered around understanding disability and advocating against the ableism of PWDs while 'accessibility research' is about the development of technologies for PWD. Although seemingly intertwined, an important critic that accessibility research has received is the way it has ignored the voices of PWD and oversimplified their impairments (Hofmann, Kasnitz, Mankoff & Bennett, 2020).

The integration of disability studies in accessibility research is related to the use of disability simulation whereby able-body people embody a disability through a tool or device, such as degraded spectacles in the case of low vision. Although the simulations are designed based on the PWD's self-reported symptoms and expert opinions, it is not entirely sure whether they are appropriate in the context of user testing (Tigwell, 2021). On one hand, their use would be beneficial in resolving the current limits of accessibility research such as the difficulty of recruiting participants, and the increased expertise, cost, and time needed (Choo et al., 2019; Mack et al., 2021). For instance, experiencing an artificial impairment to make able-body people develop a more compassionate view of the living situations of PWD has been shown to produce positive experiences such as increasing empathy and motivation to be more accommodating towards PWD (Silverman, 2015; Juniat, et al. 2019; Tigwell, 2021). Following the same idea, this practice has been used for educational purposes for able-body people as a mean to raise awareness of the non-obvious day-to-day difficulties PWD may encounter (Juniat, et al. 2019). On the other hand, these simulations can also create a false sense of understanding of the living situations of PWDs. Research has shown that the ones experiencing the simulation tend to exacerbate the negative aspects of the capability loss, making them have an overly negative view of the PWD's life experience (Nario-Redmond, Gospodinov & Cobb, 2017; Silverman, 2015). Furthermore, people with and without disabilities interact differently with ICTs due to their own set of developed abilities that are factored into their experience (Tigwell, 2021; Nario-Redmond et al., 2017; Silverman, 2015). The overly negative view of the living conditions of PWD relates to a well-researched phenomenon called the Disability Paradox. It describes the way external observers describe the quality of life of PWD as worse than it actually is (Albrecht & Devlieger, 1999). Furthermore, it has been critiqued that low vision simulations do not provide an accurate representation of the symptoms of patients due to their complexity and heterogeneity (Ates et al., 2015; Jones et al., 2020).

However, the goal of simulating disability is not to replicate exactly the disabled experience and to replace the involvement of PWD in research, but rather to allow for a 'first-person approach' during the user testing of an ICT. Therefore, the goal of researching disability simulations in HCI is not to reduce PWD to their disability but to give them agency and control over the advancement of new technologies by using their expert input into the development or design process of ICTs (Hofmann et al., 2020; Mack et al., 2021).

2.2.2 Neurophysiological Measures

For user testing, objective measures of UX such as neurophysiological and psychophysiological measures (i.e., attention, cognition, emotion) tend to be favoured over subjective measures such as self-reported perceptions measured through interviews and questionnaires due to their objectivity and better reliability (Maia & Furtado, 2016; Riedl & Léger, 2016; Zaki & Islam, 2021).

The most common type of neurophysiological measures that record responses from the face and head are electroencephalography (EEG), emotion detection, electrocardiogram (ECG [or EKG]), eye tracking, electrodermal activity (EDA) and electromyography (EMG), in order (Zaki et al. 2021). The measures are recorded with devices that require unobstructed access to some body parts. EEG measures brain activity through several electrodes placed on the scalp. Emotion detection measures emotions through facial muscle movements coded with automatic facial analysis. ECG measures heart rate through electrodes placed under each clavicle and on the left rib. Eye tracking (i.e., oculometry) measures eye movements and attention through gaze, fixations and saccades. EDA measures skin conductance through electrodes placed most often on the hand to infer cognitive, emotional, and attentional states. EMG measures emotions through facial muscular contraction and relaxation with sensors or needles placed on the face (Riedl et al., 2016).

Several considerations should be noted when using these devices. Most of them use measures that require access to the face and head. For instance, for good quality data, EEG requires direct access to the scalp without being interfered with as it is highly sensitive. Physical pressure applied to an EEG electrode can compromise the quality of the data (Tauscher et al., 2019). Moreover, emotion detection is very sensitive to light conditions such as harsh shadows and anything that can block facial features such as a hand, hair, piercings, or glasses as it can significantly decrease the accuracy rate of the expression recognition (Giroux et al., 2021; Hadinejad et al., 2019; Terzis, Moridis, & Economides, 2010; Terzis, Moridis, & Economides, 2013). Additionally, eye tracking's data quality can be affected by lenses of glasses with a strong prescription, dirty, with a tint or anti-glare coating, and contact lenses can affect the reflection of the infrared light (Singh and Singh, 2012). These factors may play a role in the compatibility with low vision simulation, as they are placed on the head and face as well.

2.3 Methodology

This literature review is narrative (Green, Johnson, & Adams, 2006; Paré, Trudel, Mirou & Kitsiou, 2015). It focuses on building an understanding of the current literature by bringing together interdisciplinary literature. The review takes knowledge from medicine and ophthalmology to understand low vision and VIs, from sociology to understand the impact of researching disability and of low vision, from engineering to understand the types of development made on the low vision simulations, and from HCI and UX to identify the potential applications of the topic. The search for the literature started in November 2021 and ended in January 2023.

2.3.1 Databases

Before searching on specific databases, preliminary searches were done on Google Scholars to be able to identify relevant keywords and synonyms (Appendix A), narrow down specific fields of research, as well as identify journals and publishers.

First, to build an understanding of low vision and VIs at large (e.g., presentation and progression of symptoms, types of diagnoses, affected population, social and economic impacts), searches were done on medical databases such as PubMed, and National Eye Institute (NEI) and journals, such as Investigative Ophthalmology and Vision Science (IOVS) and Journal of Vision (JOV). Additional information relating to the societal and economical impacts (e.g., prevalence in the global society, cost on the health care system, living conditions) of low vision were done on other information resources such as Word Health Organization (WHO). The search was focused on developing a comprehensive understanding of the various conditions of low vision patients. Engineering-related searches were primarily taking information from well-known publishers such as ACM and IEEE, which have journals and conferences that relate to simulations, accessibility research, and HCI and UX. Furthermore, due to the specificity of the research objective, backward and forward searches were a useful method to identify important literature in the field. From there, the formulation of the research question was done, and the inclusion and exclusion criteria were determined.

2.3.2 Inclusion and Exclusion Criteria

The type of literature that is selected includes articles published in journals and conferences exclusively written in English. No exclusions were put on the date of publication. Furthermore, the selection of the simulation tools and devices that are being discussed in this literature review has three distinctive criteria: immersive, off-the-shelf, and see-through (real environment). (1) The focus on immersive simulations (i.e., affecting the whole visual field [VF]) excludes 2D-based simulations (i.e., affecting only the display) such as browser extensions and software, as well as gaze-contingent displays. (2) Off-the-shelf simulations exclude papers that focus on the development of hardware and software, on methods that require custom-made simulations such as contact lenses, and on the testing of home-made simulations using instruments such as paint and markers. (3) Finally, see-through devices exclude the use of virtual environments (i.e., Virtual Reality [VR]) as they do not represent real-environments. In addition, studies that used simulation tools that fit the inclusion criteria, but did not specify which specific simulation was used, were also excluded.

The outcome of the search yielded two different types of off-the-shelf immersive low vision simulation (i.e., analog simulation spectacles and AR HMDs). In total, six types of analog simulation spectacles were identified. They were investigated through 23 articles. For the second type of simulation, AR HMDs, three simulations were identified, and each is investigated through an article. The date of publication of articles ranges from 1998 to 2021.

2.4 Findings

This section provides a discussion on the findings gathered from the literature search on low vision simulations and their compatibility with UX neurophysiological measures. The first section, analog simulation spectacles, discusses each simulation by starting with their description followed by ways they have been used in accessibility research. Finally, the compatibility of each simulation with neurophysiological devices (i.e., EEG, emotion detection, eye-tracking, and EMG) is explored. This structure is maintained for the second section on HMDs using AR. Furthermore, through the findings, research gaps are highlighted.

2.4.1 Analog Simulation Spectacles

There exist a variety of spectacles to simulate different types of low vision conditions, either representing a static image of a specific VI or symptom through a degraded lens. The benefit of using spectacles is their ease of use, immersiveness, and low cost. As these tools are analog, they are accessible to various levels of expertise and tend to be inexpensive compared to other types of low vision simulations. The spectacles create an immersive experience by impacting the entire VF when worn on the eyes (Ates et al., 2015). To illustrate, when using a desktop or laptop, the keyboard and the hands would also be affected by degraded vision, not only the screen like it would with 2D-based simulations. There are various types of validated simulations spectacles kits that are available such as the *Cambridge Simulation Glasses* (University of Cambridge, n.d.), *Good-Lite Simulation Glasses* (Good-Lite, n.d.), *Sim Specs* (ConnectToDesign, (n.d.), *Fork in the Road* (Fork in the Road, n.d.), and the *Zimmerman Low Vision Simulation Kit* (Zimmerman Low Vision Simulation Kit, n.d.). Each kit is made up of spectacles simulating different impairments or symptoms of varying intensities, shown in Appendix B.

Some simulation spectacle kits offer the ability to vary the simulated impairment. The *Cambridge Simulation Glasses* reduces visual acuity (VA) and the ability for spatial and pattern discrimination by reducing contrast sensitivity (CS; Xiong et al., 2020). The severity of the simulated impairment can be manipulated by stacking multiple glasses. Wearing up to two (20/40 VA) or three (20/60 VA) glasses is effective in building empathy and ensuring visually accessible design (Goodman-Deane, Waller, Collins & Clarkson, 2013), and wearing up to five simulates legal blindness (Clarkson, Coleman, Hosking & Waller, 2011). Also, the *Zimmerman Low Vision Simulation Kit* is made with lenses that can be removed from the frames, allowing to simulate varying symptoms in each eye. This allows for a more realistic simulation as VIs are often asymmetric between each eye resulting in a better-seeing eye (Choi, Jung, & Jee, 2018; Chow-Wing-Bom, Dekker & Jones, 2020).

Analog simulations have been investigated in research in various fields, often used in 'real-world' settings. The different studies presented have tested various types of simulations in naturalistic environments and showed that they effectively reduce visual function.

Very few studies have looked at their use in the context of user testing. In a study by Angeleska et al. (2020), they used the *Cambridge Simulation Glasses* to evaluate the accessibility of a user interface (UI) for autonomous driving cars. Their goal was to determine the needs of users with low vision and accessibility design requirements when it comes to the accessibility of an interface. Another study used the same simulation in the context of user testing (Goodman-Deane et al. 2013). Through the testing of physical products, they found that they accurately reduced VA and helped to examine some of the products' features visibility. Although the product being tested was physical and not digital, the conclusion favored the use of the glasses in the context of a user test.

In the context of medical education, it was found that simulating low vision using the *Sim Specs* has helped medical students adapt their approaches towards low vision patients to make them more appropriate through Instrumental Activities of Daily Living (IADL), such as making tea, filling dosette boxes and navigating/walking (Juniat, et al. 2019). Another study focusing on

IADL found that using the *Fork in the Road* macular degeneration (i.e., central scotoma 6/120) simulation increases the time to perform activities such as using the bathroom, unpacking groceries, climbing stairs, walking indoors and outdoors, and crossing the street (Copolillo, Christopher & Lyons, 2017). Furthermore, they also found that the simulation has an effect on postural adjustment while performing IADL. The simulation had an effect on how often participants needed to stabilize themselves, pause, and misstep. Other studies have also supported the use of simulated low vision and postural adjustment (Anand, Buckley, Scally, & Elliott, 2003; Heasley et al., 2004).

Simulation spectacles have also been used to identify the implications of low vision in navigation such as driving (Marrington et al., 2008; Rae et al., 2016). Using the *Good-Lite Simulation Glasses*, it was found that the cataract simulation reduces the participants' hazard detection using a video-based test. Their findings are in line with what is seen in lower hazard detection due to CS loss in older adults (Marrington et al., 2008). In another study, the *Cambridge Simulation Glasses* were used to determine the effects of reducing VA and CS in the ability to achieve the UK's driving vision standard. The simulation allowed them to manipulate the severity of the VI by making the participants wear multiple pairs of spectacles. Through their experiment using a ETDRS style logMAR chart and a Snellen layout chart, they determined that the reduction of VA and CS was in line with what is found in mild and moderate cataracts (Rae et al., 2016).

Another context in which simulation spectacles have been used effectively is in navigation in a built environment. In a study by Zallio et al. (2021), the *Cambridge Simulation Glasses* were used to determine the accessibility of a built environment by navigating in a building. It was concluded that using simulation spectacles was the most valid method to determine the accessibility of built features such as staircases and signage compared to determining accessibility based on personal belief and taste, the judgement of an expert (i.e., trained consultant), and heuristics guidelines (Zallio et al., 2021). Moreover, the *Fork in the Road* was used in another study to determine the legibility and comprehension of signage in a hospital through the simulation of five different VIs (diabetic retinopathy, glaucoma, cataracts, macular degeneration, and hemianopsia). The participants in the simulation condition reported more problems with the signage and spent more time wayfinding (1.9 times longer) than the control group (i.e, normal vision). The nature of the reported problems was related to size, illumination, position, and contrast. Some have also reported not noticing the signage. They also displayed different behaviors such as walking more carefully and slower, paying more attention, and stopping more often. This study also concluded that the simulation is effective in giving recommendations about potential obstacles in the environment (e.g., misinterpreting steps and floor) that are not present in the guidelines for buildings and facilities in the Americans with Disabilities Act for visual accessibility (Rousek, Koneczny & Hallbeck, 2009; Rousek & Hallbeck, 2011a; Rousek & Hallbeck, 2011b). The effectiveness of the low vision simulations is demonstrated by its effect on the participant's visual ability and behaviors, as well as by their ability to provide recommendations that extend beyond accessibility guidelines and expert opinions.

In the context of sports performance, simulating low vision has been shown to have an effect on the ability of the athletes. For instance, in a study by Allen et al. (2018), the effect of low vision was measured on elite riffle shooters' performance. It was found that their performance was negatively affected by reduced CS and VA while wearing the *Cambridge Simulation Glasses*. Similarly, in a study by Satlin et al. (2021), using the same simulation in addition to VF loss using a custom simulation by the University of Waterloo (Canada), they found that the performance of nordic and alpine skiers was negatively affected by mild VI. These studies, like the one about UK's driving standards, are contributing to the regulations and eligibility requirements for parasport participation (Allen et al., 2018; Satlin et al., 2021) and driving (Rae et al., 2016) as they have shown that simulated reduced visual ability also replicates the effects of reduced performance seen in people with low vision.

Moreover, simulation spectacles have been used to investigate the relationship between low vision and cognition. In a study by See et al. (2010), it was found that CS (simulated with *Good-Lite* cataract spectacles*)* negatively impacts cognitive performance measured through accuracy and speed using letter matching (perceptual speed) and symbol recall (short-term memory) tasks. Similarly, using the *Fork in the Road* to simulate VA loss, it was found that simulated vision loss negatively affected cognitive testing performance when compared to normally sighted participants using the Montreal Cognitive Assessment (Stark et al., 2022). Other studies evaluating the effect of low vision on cognitive performance have come to similar conclusions, demonstrating that using simulation glasses also impacts cognitive function tested with validated scales (Stark et al., 2022).

The existing research on simulation spectacles is multidisciplinary. They have been shown to effectively affect cognitive performance, physical ability, perception and behavior, leading to changes in how people interact with their surroundings. While there is not yet much research on their use for user testing, the body of existing research provides strong support for the use of spectacles in this context.

Compatibility with neurophysiological measures

There is a lack of research on the use of spectacles on digital products for user testing on mobile, laptop, and desktop interfaces. When the compatibility with neurophysiological measures requiring access to the face and head such as EEG, emotion detection, and eye tracking used in UX research has to be determined, three factors need to be taken into consideration: frames, montage, and lens.

The frames of the spectacles are important to consider for compatibility with emotion detection analysis. When the frames of the glasses are thicker, they could hide facial features that are important for accurate emotion detection (Hadinejad et al., 2019). For example, *Cambridge Simulation Glasses* and *Good-Lite Simulation Glasses* are made of a flexible, light but thick frame which can hide facial features such as the eyebrows. Due to the composition of the frames, they would have to be modified to be narrowed to be suitable for an emotion detection software. The *Fork in the Road* and *Zimmerman Low Vision Simulation Kit* are goggles made of a sturdier and more prominent frame that hides a larger portion of the face, making their compatibility with emotion detection difficult. Finally, the *Sim Specs* do not have a frame, instead, the VF is degraded by a unique lens. This kit is the one that hides the less facial features, making it potentially the most compatible spectacle kit with emotion detection.

As for the montage, it mostly determines the spectacles' compatibility with EEG, which records cerebral activity through electrodes placed on the scalp using a cap to hold them in place (Kim, Jeon & Biocca, 2018). Most glasses are worn with branches that go behind the ear, like typical prescription glasses. However, the *Zimmerman Low Vision Simulation Kit* and *Fork in the*

Road have elastic bands that lay around the head, on the scalp, to hold the goggles in place. This elastic band would interfere with an EEG cap, making the recording of cerebral electrical signals difficult to record (Kim et al., 2018).

The lens of the simulations would determine their compatibility with the eye tracking device. As a clear view of the cornea and the pupil is required, certain simulated impairments would not allow for eye tracking. For example, lenses presenting symptoms of impairments such as advanced glaucoma or retinitis pigmentosa that can cause tunnel vision would only have a small central dot allowing the able-body participant to view from it, blocking the peripheral VF. The *Zimmerman Low Vision Simulation Kit*, the *Fork in the Road* and the *Good-Lite Simulation Glasses* simulate tunnel vision. Another example is central field loss, where the central vision is affected with a central scotoma. This type of simulation has black or white dots in the center of the lens blocking central vision (*SimSpecs, Fork in the Road, Good-Lite Simulation Glasses, Zimmerman Low Vision Simulation Kit*). When using webcam-based eye tracking, the gaze of the participants needs to be visible, making it difficult to be used with glasses that obstruct the view of the eyes (Valliappan et al., 2020). For infrared light eye trackers, enough light should pass through the lens for proper tracking of the eye movements (Carter et al., 2020). Some simulations could hinder the quality of the eye tracking data while others might not, such as simulated VA loss and CS (*Cambridge Simulation Glasses*). This type of simulation is represented by a blurring of the lens seen in cataracts and diabetic retinopathy that could allow for effective eye tracking. There is a type of eye tracking called electrooculography (EOG) which measures eye movements through electrical potential signals around the eyes with five electrodes placed around both eyes (Singh et al. 2012). The advantage this method holds over other eye trackers requiring light reflections on the eye, is that it is not sensitive to external lighting and visibility of the eye. Additionally, the sensors of the EOG could effectively be integrated in glasses or goggles (Bulling, Roggen, and Tröster, 2009; Steinhausen, Prance and Prance, 2014). In a study by Bulling et al. (2009), EOG was successfully integrated into wearable and lightweight goggles to be used for HCI research. Their device showed accurate real-time eye tracking data that have been tested on a desktop screen (Bulling et al., 2009). This device could be used in combination with a simulation spectacle by integrating a simulation lens rather than a clear one, giving the possibility to track eye gestures effectively and accurately without suffering from data loss due to poor visibility of the eye.

Low vision can affect different anatomical structures of the visual circuit (e.g., lens, retina, optional nerve, optic chiasm, occipital cortex) and the symptoms can vary depending on light conditions and gaze, making VIs dynamic rather than static (Jones et al., 2018). Simulating static visual symptoms rather than dynamic ones make the low vision simulation with spectacles less realistic. Nonetheless, the whole VF remains degraded. This gives the opportunity for validation of the spectacles through typical ophthalmology tests that can easily be integrated into an experimental design such as the Landolt C, EDTRS letter chart (Goodman-Deane et al., 2013) or the Freiburg vision test (FrACT) that can be used on a desktop screen through calibration (Bach, 2006) which may be a more suitable method for user testing of an ICT.

2.4.2 Augmented Reality (AR)

AR is a technology that adds computer-generated images onto the real-world environment, creating a mixed-reality environment that enables users to interact with both the physical and virtual worlds simultaneously. By using HMDs (i.e., wearable displays) equipped with cameras to create a stereoscopic vision, a see-through display can be created, allowing for an immersive experience affecting the whole VF (Ates et al., 2015; Krösl, 2021). This technology has been utilized to produce dynamic low vision simulations, particularly in the context of user testing (Choo et al., 2017). Rather than a static image affecting the VF like with simulation spectacles, the presentation of symptoms has the possibility of being dynamic (Krösl, 2021). Furthermore, some AR technology has recently been used in combination with eye tracking which allows for the simulated symptoms to be gaze-contingent, making the simulation even more realistic (Krösl, 2021). Finally, as AR is used with HMDs, it allows for mobility (Jones et al., 2020).

There exist different types of head-mounted see-through AR displays used for low vision simulation (Appendix C). These studies use hardware and software available commercially, however they require manipulation to integrate the simulation adequately (Ates et al., 2015; Jones et al., 2020; Krösl, 2021).

In a study by Jones et al. (2020), the Vive headset was used with OpenVisSim (i.e., open-source software rendering simulated impairments in real-time) to simulate glaucoma with gaze-dependency. Participants had to navigate through a maze, and it was found that the participants in the simulated condition took more time to complete the maze and that they displayed more and similar head and eye movements to what is seen with people who have glaucoma. This type of set-up showed that normally sighted participants can experience, through the simulator, similar functional difficulties of PWD who have glaucoma. Moreover, this study manipulated the location of the VF loss, which is possible with OpenVisSim (Jones et al., 2020).

In a study by Choo et al. (2017), experienced web developers compared the use of AR see-through display in combination with VR. The participants were holding a real phone that was captured with cameras on the HMD and was emulated in VR through a computer. They used a cataract simulation and accessibility guidelines (WCAG 2.0) with the use of an automatic accessibility checker (Google Accessibility Scanner) to assess the accessibility of a website on a mobile phone using *Empath-D* (simulation). The AR HMD allowed participants to be more accurate in their identification of usability issues, which they were able to also find more of. This study showed that evaluating the accessibility of a website's design using AR allowed for more concrete recommendations than with the existing methods. This study concludes that using *Empath-D* is appropriate for developers to use for testing (Choo et al., 2017).

Another popular AR device that has been used is the OculusRift. In a study by Ates et al., 2015, the software SIMVIZ to simulate the common VIs was used (i.e., macular degeneration, diabetic retinopathy, glaucoma, cataracts, color blindness, diplopia) to compare the simulation with a smartphone-based simulator. It was found that the AR HMD provided a more immersive simulation, and it allowed for more potential in detecting accessibility problems than the screen-based simulation (Ates et al., 2015).

These studies show that using AR HMDs in usability evaluations has shown to be effective. The simulations created are immersive and more realistic than other methods (e.g., non-immersive, static). Although AR HMDs can provide greater flexibility in simulating low vision symptoms, there is a learning curve for UX researchers who are using them for the first time (Choo et al., 2017). Nevertheless, once overcome, researchers can recreate impairments in a more realistic manner by using AR HMDs to represent symptoms (Choo et al., 2017; Jones et al., 2020).

Besides the usability of AR HMDs being more difficult to use than with analog spectacles, other known drawbacks to AR are that the VF is constrained, and people using the device have reported feeling dizzy, being fatigued and having headaches after wearing them (Zhang & Codinhoto, 2020). Furthermore, over time, visual fatigue can also occur. The quality of the image displayed in a VR headset is lower than the human eye, which can be exacerbated over time creating a larger reduction in VA (Krösl, 2021). These limitations are important to consider when using AR with participants.

Compatibility with neurophysiological measures

The compatibility of AR HMDs and neurophysiological measures requiring head and face access depends greatly on the nature of the device used. Automatic emotion recognition requires visual access to the face. As the HMD covers most of it, it is not possible to infer emotions based on facial expressions. However, there exist other methods to measure emotional arousal such as EDA or ECG which infer emotional as well as attentional and cognitive responses (Riedl et al., 2016). As for eye tracking, two of the three devices presented were used in combination with eye tracking. In this context, the eye tracking was used to adapt the positioning of the simulation according to the gaze of the participant (Choo et al., 2017; Jones et al., 2020). Although it was feasible, these studies did not look into the use of the eye tracker to analyze information from the gaze such as fixation, saccades and eye movements. Finally, as for EEG, the montage of the HMD needs to be adapted for it to be used accurately. The montage of a HMD is made with flexible rubber or elastic bands placed on the head to hold the device in front of the eyes. For example, the Oculus Rift which has been used for low vision AR simulation (Ates et al., 2015) uses a 3-axis headband (Kim et al., 2018). This HMD in combination with an EEG cap may lead to a reduced quality of the recordings of the electrodes due to the physical pressure the montage applies on them. Two drawbacks can result from this: misplacement of the HMD preventing the AR or VR environment, or a reduced quality of the EEG recording. Consequently, adaptations to both or either system are needed to be compatible, keeping in mind that each HMD and EEG can have varying configurations. As a solution, HMD montages or EEG channel configurations can be adapted. Some studies have focused on the development of compatible systems, such as the M.I.N.D brain cap. Other studies have adapted the HMD, such as in a study by Terzis et al. (2013) where they changed the positioning of the battery back and of the montage. Although the compatibility of both is continuously advancing, it still needs to be explored (Terzis et al., 2013). This limitation is important to consider when choosing a HMD as a low vision simulation with EEG.

2.5 Discussion

This review shows that using low vision simulations can go beyond internal use during iterative development and design process, and instead be used with able-body participants during user testing. Immersive low vision simulations that are easily available to use for user testing are simulation spectacles and AR integrated in HMDs. Both categories of simulations have been shown to be effective in replicating the effects of low vision on various types of performance metrics, including UIs, through empirical research. Furthermore, simulating low vision has also shown to be more useful to evaluate the accessibility of a UI through user testing compared to the current methods such as accessibility guidelines and automatic evaluation software programs. Compared to AR, there is a relatively large body of research on simulation spectacles and there are a variety of brands simulating different impairments to choose from. While simulation spectacles are easy to use, inexpensive and immersive, they do not represent low vision conditions as realistically as AR can. Despite the need for training on how to use them and their increased cost, the advantage AR technology offers is its ability to create dynamic symptoms that correspond to the user's gaze in real-time, as opposed to static symptoms. However, this method is still in development (Jones et al., 2020). Even if the literature on this type of technology is limited, it has been used in the same context of use this literature review investigates.

Additionally, this literature review uncovered the limitations of using simulations with neurophysiological measures used to measure UX. The use of the EEG might not be compatible with simulations that are worn with elastic bands around the head, such as goggles (i.e., *Fork in the Road* and *Zimmerman Low Vision Simulation Kit*) and HMDs. However, there are current alternatives that offer the possibility to combine an EEG cap with HMDs (Kim et al., 2018). Also, simulations such as goggles (e.g., *Fork in the Road* and *Zimmerman Low Vision Simulation Kit*) and HMDs hide most facial features which hinder the use of emotion detection. Similarly, it is unclear how accurate the tracking of eye movements such as saccades, fixations and gaze is. The spectacles with lenses that cover most of the eyes (i.e., simulating central or peripheral vision loss or scotoma) can be an obstacle for valid eye tracking data. However, lenses that have an overall blur simulating VA and CS loss (e.g., *Cambridge Simulation Glasses*) might be more promising with eye tracking. As for AR, some studies have used eye trackers to infer gaze but not to measure UX (Jones et al., 2020). Overall, these obstacles emerge from the known limitations of these measures, however, without testing no definite conclusions can be drawn.

This literature review contributes to the field of HCI, and specifically UX research and user testing by giving an overview of what types of immersive low vision simulations are available for UX researchers to evaluate user perception, behavior and performance in a more realistic setting. The insights gained from these simulations can be highly valuable and can provide useful information to guide the evaluation of web content on UIs. They can also be integrated in HCI research that is not specifically centered on accessibility. These simulations provide an additional method for the promotion of more inclusive research. Through the findings, it is shown that the accuracy and effectiveness of the two types of immersive simulations, spectacles and AR, are valid in simulating low vision when comparing their experience with the ones of actual low vision participants. Beyond the testing of an ICT, measuring the UX of participants through neurophysiological measures while experiencing a simulation remains to be tested, as some limitations of these measures become important.

One limitation of this literature review is that the simulations addressed were narrowed down according to specific criteria: immersiveness, availability and real-environment setting. Although the findings gathered are specific, there is a wide range of devices that have not been discussed that could be used in the context of a user test. Some examples of other simulation are home-made spectacles, contact lenses, 2D-based simulations, and VR.

Home-made methods have been excluded as they might not be valid in replicating actual low vision. Although the representation of VI symptoms would not be accurate, the effect of the visual loss can be measured through ophthalmology tests. They also are a relatively cheap option. The severity and the nature of the symptoms can easily be manipulated through the use of household products such as paint, markers and tape (Zagar & Baggarly, 2010).

Contact lenses can simulate VIs by creating a partial occlusion of the lens. This method can be used to simulate different impairments by opacity of the contact lenses for example which reduced perceived VA and CS (Almutleb & Hassan, 2020; Butt et al., 2015; Czoski-Murray et al., 2009). Although they simulate a static image, they follow eye movements, making them more realistic than spectacles (Macnamara et al., 2021). However, medical and ophthalmology experts are required to create a contact lens that is adapted at the micrometre level for each participant to follow the gaze appropriately (Almutleb, Bradley, Jedlicka & Hassan, 2018).

2D-based simulations have been widely used and researched in the context of testing (Ates et al. 2015). Many different software and browser extensions allow the user to visualize their webpage through a degraded view, such as EASE (Evaluating Accessibility through Simulation of User Experience). They have been shown to be helpful in identifying usability issues relating to accessibility, but using alternative simulations has been shown to be more effective (Ates et al., 2015; Mankoff, Fait & Juang, 2005; Zhang et al., 2020). Furthermore, they do not offer a realistic simulation and fail to replicate the visual ability and behavior of people with low vision (Zhang et al., 2020). However, this simulation is low cost and often free, and is easy to implement (Zhang et al., 2020). Furthermore, can be used with neuropsychological measures without additional constraints as no additional device needs to be worn to cover the VF.

As for VR, they do not simulate vision loss in a real environment, but in a 3D virtual one. With continuous technological advances, VR provides increasingly realistic renderings. In the context of simulating disability, they have shown to be effective in simulating capability loss seen in older individuals such as decreased mobility. They have mostly been used for evaluating the accessibility of built environments and promote empathy (Zhang et al., 2020). Although they are not compatible with all types of neurophysiological measures, some technological advances allow for gaze tracking. Similar to AR in HMDs, gaze tracking allows for a more realistic simulation that creates a stereoscopic view that can be independent in each eye (Jones et al., 2018). However, in the context of a user test on a mobile, laptop, and desktop interfaces, VR is used as AR through stereoscopic cameras and by emulating the real interface in a virtual environment (Choo et al., 2019).

Finally, another limitation of this review is due to its methodology. This is a narrative literature review, meaning the search of the existing literature was not done systematically. It was done in a selective way rather than a comprehensive way. Consequently, this methodology can create a selection bias in the data reported. As a way to reduce this risk of bias, the inclusion and exclusion criteria for the selection of the papers relating to the use of low vision simulation was objectively defined according to the research question. Moreover, the goal of this narrative review is not to provide a generalization of the existing body of knowledge, but rather, it is to provide a basis for future research. Considering the limited literature on the topic, this type of review allows to identify potential research gaps through a qualitative report of the findings.

Overall, there exists a variety of simulations that can be effectively integrated in user tests, however not all types are suitable. Analog simulation spectacles seem to be a simpler alternative. Their ease of use, immersiveness, availability and validation in empirical research would make them more favorable than AR-based simulations due to the skill set required to operate them. In fact, one of the motivators for using disability simulations in HCI research is to alleviate the drawbacks of accessibility research brings. Thus, the implementation of an additional device, method or tool in an experimental design should not be adding strain to the already complex process of conducting accessibility research. Future research in accessibility should investigate the use of a specific simulation discussed with neurophysiological measures in the context of a user test by integrating actual low vision participants as well as normally sighted participants as controls. This literature review helps establish the current state of the research on simulations and identify existing gaps in the literature.

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Chapter 3

Can we replicate impaired vision with simulation glasses in computer-based task? An Eye Tracking Validation Study*

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Abstract: With growing pressure to develop accessible apps and websites, designers, developers or User Experience researchers also face the challenge of recruiting people with disabilities to conduct inclusive usability evaluations. While many researchers rely on disability simulations to identify usability issues, others argue that disability simulations cannot fully replicate the behavior and the lived experience of people with disabilities. This paper presents a study that investigates whether we can replicate the visual search behavior of low vision people on a computer interface with normally sighted participants experiencing a visual disability simulation. A total of 47 participants, including 9 low vision people, and 38 normally sighted participants with and without visual disability simulation glasses, performed computer-based vision tests and visual search tasks. Using eye tracking, we show that the disability simulation tends to replicate the visual search behavior of low vision participants.

Keywords: Accessibility, Visual Impairment, Disability Simulation, Eye Tracking, Visual Search

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3.1 Introduction

In 2017, it was reported that over five million people in the U.S. faced challenges accessing information and communication technologies (ICTs) due to low vision, and this number is expected to nearly double by 2050 due to the aging population [1,2]. Accordingly, increased effort has been made to make apps and websites more accessible since the World Wide Web Consortium (W3C) introduced the Web Content Accessibility Guidelines (WCAG) in the mid-1990s. As of 2022, 96.8% of the million most important websites' homepages still do not conform with the WCAG 2.0 guidelines [3]. In other words, these websites are still not accessible to people with visual impairments (VIs) and web inaccessibility remains a pervasive issue [36]. The ramifications of this are important as our reliance on ICTs continue to grow. Web inaccessibility can create barriers for people with low vision's access to essential activities carried online such as work, education and communication [37].

Consequently, UX researchers are encouraged to include people with disabilities in the development cycles of apps or websites on user interfaces (UIs). However, they also face the challenge of recruiting visually impaired people to conduct usability evaluations [4,5]. This population tends to be of older age and suffer from comorbidity that can make the testing of apps and websites increasingly demanding [10], [38]. Furthermore, there is a lot of heterogeneity in the presentations of symptoms, which makes recruiting participants with the same level of impairment additionally challenging [8]. Finally, there are increased resources associated with recruiting PWD for user testing (e.g., time, cost, training) that might not be available to all [39].

A circumvention to this issue is to recruit able-body participants and simulate a disability through the replication of symptoms associated with a disability (e.g., wearing a blindfold to simulate blindness) [39]. This method has been used by scholars in Human-Computer Interaction (HCI) and other fields where they attempt to identify usability issues by assessing how able-body participants experiencing a disability simulation interact with a software [6,7,8,9]. However, it has been argued that visual disability simulations do not accurately replicate a visually impaired person's behaviors in activities of daily living, including computer-based tasks [10]. These claims are primarily based on low vision participants' self-reports and do not target their use in the context of a participatory user test [10,11]. Moreover, the goal is not to exactly replicate the experiences of PWD, but rather to allow for a first-person perspective through the use of a simulation to get insights about the accessibility of a software with the effects of low vision [40].

There exist several different types of low vision simulations available for user testing, including analog tools such as contact lenses and spectacles, 2D-based software programs, and augmented and virtual reality. Out of these options, analog simulation spectacles seem to be the most convenient to integrate for user testing. Their ease of use, immersiveness, availability and their validation in empirical research would make them more favorable [14,15,16,17]. Currently, there is a lack of empirical evidence comparing the behaviors of low vision people to those of normally sighted users experiencing a visual disability simulation on a UI.

To investigate the feasibility of conducting valid participatory user testing with low vision simulation, this study explores the following research question: To what extent does the visual search behavior of normally sighted participants experiencing a visual disability simulation can replicate the visual search behavior of people with low vision? To address this question, this study investigates the effect low vision simulation has on visual behavior on normally sighted participants. The visual behavior of the participants was compared to two other groups, controls and low vision participants, in a between-subject experimental design using 46 participants, including 9 low-vision participants. Through the use of eye tracking, the three groups of participants performed an initial assessment of the contrast sensitivity (CS) of each group to get an objective measure of the effect of the simulation. Secondly, they performed a visual search task in a high contrast and low contrast condition, where their reaction time (RT) and the ratio of fixations over saccades were measured. Finally, the participants conducted several naturalistic tasks on a banking platform that will be analyzed in future works.

Due to the impact of low vision on the ability to perceive visual features, we expected to find poorer performance for the low vision participants (simulated and real) compared to controls. Our results suggest that the visual search behavior of normally sighted people wearing disability simulation glasses is comparable to the one of people with low vision. This promising finding will allow us to analyze the subsequent naturalistic tasks by getting a deeper understanding on the way the low vision simulation affects visual search behavior.

Our study aims to demonstrate the feasibility of using low visual simulations in participatory user testing on UIs. This brings accessibility research one step further towards a better understanding of how visual disability simulations allow normally sighted people to identify usability issues in apps and websites that are experienced by low vision people.

3.2 Literature Review and Hypothesis Development

This section reviews the related literature that contributed to the development of the hypotheses. The research question was investigated through three hypotheses related to the perception of contrast, the reaction time and the ratio of fixations over saccades.

3.2.1 Cambridge Simulation Glasses.

Developed by the University of Cambridge, the Cambridge Simulation Glasses are part of a toolkit of three simulation types that can be used in combination [14]. The glasses simulate low vision, they mildly restrict the ability to see fine details and contrast differences (Fig.1). They do not simulate a specific disability, but a general visual capability loss by reducing VA and CS [12], [17]. Both measures provide complementary information when evaluating loss of visual function as VA determines the ability to see fine details and CS determines the ability for spatial and pattern discrimination [13]. For more severe symptoms, multiple glasses can be stacked in front of another (Table 2). Wearing two to three pairs of glasses is effective when designing for visually impaired and older users in building empathy and ensuring visually accessible design [14], [17]. Wearing up to six simulation glasses simulate the vision of a legally blind person [17].

Fig. 1. Cambridge Simulation Glasses [17]

The Cambridge Simulation Glasses have been used in several research settings [14,15,16,17,18], [42]. They have shown to effectively decrease the visual ability of normally sighted participants, which impacted their ability to perform specific tasks. The research settings the simulation have been used in also use their findings to make generalizations of the effects of actual vision loss on performance. For example, they have been used in a medical context, where the researchers show the effect of reduced VA and CS on the ability of radiographers to identify anatomical structures in clinical images [15]. Furthermore, they have also been used to contribute to the eligibility criteria of parasport participation by showing the effect of reduced VA and CS on riffle shooting accuracy and alpine and Nordic skiing performance [16], [42]. Finally, they have also been used to conduct usability evaluations of the accessibility of UIs to determine the needs of users with low vision [16].

Table 2. Level of visual acuity per Cambridge Simulation Glasses worn [12], [20].

Level of Vision Impairment	Visual Acuity	Number of Glasses	Reduced Acuity by (LogMAR)	Visual Acuity (VA)
Normal vision	Starting at 20/20	0	0	20/20
Mild	From 20/30 to 20/60	1	0.08	20/24
		2	0.29	20/40
		3	0.49	20/60
Moderate	From 20/70 to 20/120	4	0.74	20/110
Severe (legally blind)	Starting at 20/200	6	1.3	20/400

3.2.2 Contrast Sensitivity Threshold and Visual Search Performance

CS is rarely assessed when evaluating visual function and impairments, but VA often is. Both are important to be measured when researching VIs. It has been shown that CS is related to the most common VIs to varying degrees such as Age-related Macular Degeneration, glaucoma, retinitis pigmentosa, and cataract [13]. Although CS and VA are independent and complementary, they are strongly correlated. In fact, measuring one can be used as a reasonable estimate of the other [24].

In visual search tasks, the literature suggests that the contrast of the target affects saccades, fixations and RT to find the target. In fact, lower contrast and visibility of the target and distractors make their discrimination more difficult and time-consuming, for the normally sighted and low vision population [29, 30]. The RT to find the target increases in low contrast conditions. With a decreased contrast of targets, the fixation duration increases, and saccade amplitude decreases as well. Hence, therpratio of fixations over saccades is bigger with lower contrast targets. These findings also hold true for reading text on a UI with low contrast, but not high contrast conditions [24].

The Cambridge Simulation Glasses degrade VA but also CS. However, their effect on CS is rarely measured compared to their effect on VA. Two studies that measured CS with the Cambridge Simulation Glasses were identified and briefly discussed in the previous section. Both studies showed that the simulation effectively reduces CS compared to controls. Furthermore, the Cambridge Simulation Glasses have shown that their effect is more pronounced in low contrast conditions compared to high contrast conditions with at least two pairs of glasses. These conditions were the examination of clinical images by radiographers. They also took more time to complete the task of identifying anatomical details [15]. Therefore, we propose three hypotheses on the effect of the low vision simulation on the performance during the visual search task.

First, (H1) the simulation will decrease the CS threshold of the simulation group compared to the control groups, but have a similar threshold compared to the low vision group. In other words, the participants in the simulation group are expected to show a significant decrease in their CS threshold, meaning a lower CS, compared to the control group, but no significant difference in CS scores compared to the low vision participants are expected.

Second, (H2) the simulation will increase reaction time of the simulation group compared to the control groups, and to a similar level compared to the low vision group in both contrast conditions. Thus, we expect the participants in the simulation group to show a significant increase in their RT, meaning a slower RT to identify the target in the visual search task, compared to the control group. No significant difference in RT compared to the low vision participants are expected in the high and low contrast conditions.

Finally, (H3) the simulation will increase the ratio of fixations over saccades of the simulation group compared to the control groups, and to a similar level compared to the low vision group. Hence, we expect the participants in the simulation group to show a significant increase in the ratio of fixations over saccades, meaning an increase in fixations and a decrease in saccades, compared to the control group. No significant difference in ratio compared to the low vision participants are expected in the high and low contrast conditions.

3.3 Methods

This section provides insights into the methodology used to carry out this laboratory experiment. Before conducting the experiment with participants, there was a pre-testing session with a low vision participant to ensure the experimental design was suitable for a population with VIs. From our pre-test, we made some adjustments to our design. This section presents the final methodology.

3.3.1 Procedure

This study was conducted in a usability lab in North America between the months of July and December 2022. We chose a between-group design approach to compare the three experimental groups. The Figure 2 shows the experimental procedure of this experiment. Only the visual tasks and the results from the eye tracker are discussed in this article.

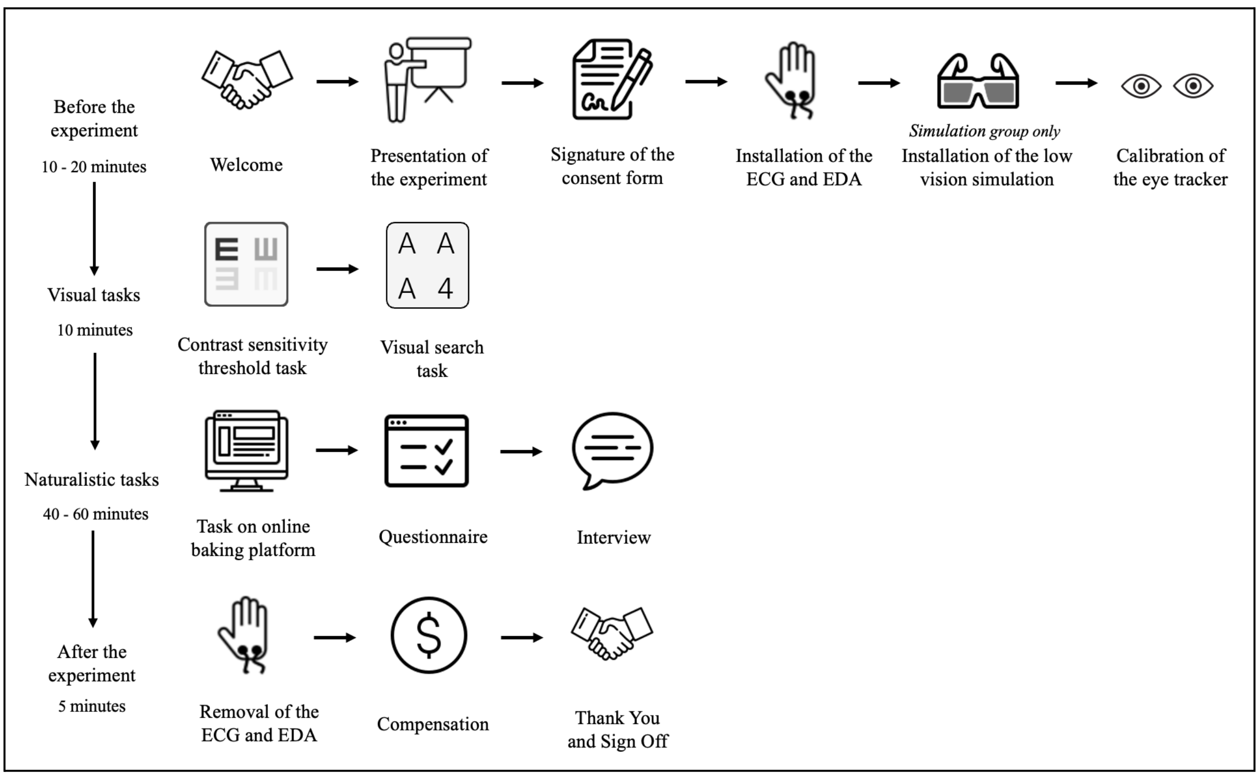

Fig. 2. Presentation of the experimental procedure.

After the presentation of the experiment, the participants signed the consent form. The participants in the low vision condition were sent the consent form before coming in for their participation, so they were able to read it comfortably, but signed it before starting the study.

They were also asked to fill in a questionnaire regarding their visual symptoms, which determined their eligibility to participate in the study. The participants in the low vision condition were also made aware they would be wearing the simulation for the duration of the experiment (1.5 hour) prior to consenting.

The experimental procedure began the installation of the electrocardiogram (ECG) and electrodermal activity (EDA) followed by an eye tracking calibration. Additionally, their facial expressions were recorded through an HD webcam. Then, all participants performed the FrACT CS threshold test in order to compare the extent to which each group can distinguish characters from a background. Subsequently, they performed a visual search task, followed by a series of naturalistic tasks on a banking website, which will be analyzed in future work along with the remaining physiological measures. In the visual search task, we aim to manipulate the contrast of specific colors used on the banking website.

The participants remained at a constant distance of 65 to 70 centimeters from the screen throughout the experiment. To keep the distance from the screen constant, each participant had a clip attached to their collar coming from the chair (Fig. 3). This clip is not restrictive in any way. If the participants leaned forward or get up, the clip would create a slight tension and then simply detach. It acted as a reminder for the participants to avoid leaning forward. As we learned from our pre-testing, this is a common behavior of people with reduced visual ability. Furthermore, the lighting conditions of the screen and the experimental room were the same for each participant.

Fig. 3. Images of the clip that was attached to the participant's collar.

3.3.2 Participants

A total of 46 participants aged between 21 and 70 (mean = 41.37; SD = 14.67) were recruited, including 23 males and 23 females. The low vision group included nine participants aged 42-70 (mean = 58; SD = 10.06) with diagnosed mild to moderate low vision conditions. They had a combination of 12 different visual symptoms. All nine had VA loss and five had CS loss (Table 3). Then, 38 normally sighted participants were randomly assigned either to the low vision simulation condition or the control condition. There were 25 participants aged 20 to 70 (mean = 37.32; SD = 13.48) wearing the low vision simulation and 12 participants aged 21 to 59 (mean = 37.33; SD = 11.38) in the control condition. Each participant signed a consent form prior to the start of the experiment which confirmed these criteria.

Table 3. Self-Reported Symptoms of the Nine Participants with Low Vision.

PXX	Low Contrast	Dark vision	Light sensitivity	Faded colors	Yellowing	Blurry vision	Acuity loss	Double vision	Central vision loss	Peripheral vision loss	Scotoma	Deformed images
P01			✓			✓	✓		✓	✓		
P02	✓	✓	✓			✓	✓	✓				
P03	✓		✓	✓		✓	✓	✓	✓	✓		✓
P04		✓	✓				✓		✓	✓		✓
P05	✓		✓			✓	✓			✓		
P06	✓		✓	✓			✓			✓		✓
P07			✓	✓	✓		✓		✓			
P08						✓	✓	✓				
P09	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	

3.3.3 Apparatus and Instrumentation

For the simulation, among our 26 normally sighted participants wearing visual disability simulation glasses (Fig. 4), 14 wore two pairs of superimposed glasses (i.e., mild VI) and the remaining 12 wore four pairs of superimposed glasses (i.e., moderate VI) [19]. These simulated VIs correspond to mild-to-moderate low vision according to the World Health Organization (Table 2) [20]. The two different levels of simulation were randomly assigned to the participants as a way to replicate the heterogeneity of symptoms found in low vision [8]. The severity of the simulation and of the low vision symptoms of the low vision group were not distinguished in the analysis.

Fig. 4. Normally sighted pilot participant wearing two pairs of the Cambridge Simulation Glasses in the laboratory experimental room.

For the eye tracker, we recorded eye movements at 60fps using a Tobii Pro Nano eye tracking device (Tobii, Karlsrovagen, Sweden). We calibrated the eye tracker using Tobii Pro Lab (Version 1.181) with a manual 9-point calibration. The target of the calibration was dynamic and larger with increased contrast (Figure 5). This target was chosen by the low vision participant during the pre-test session, and they determined it to be the most visible one.

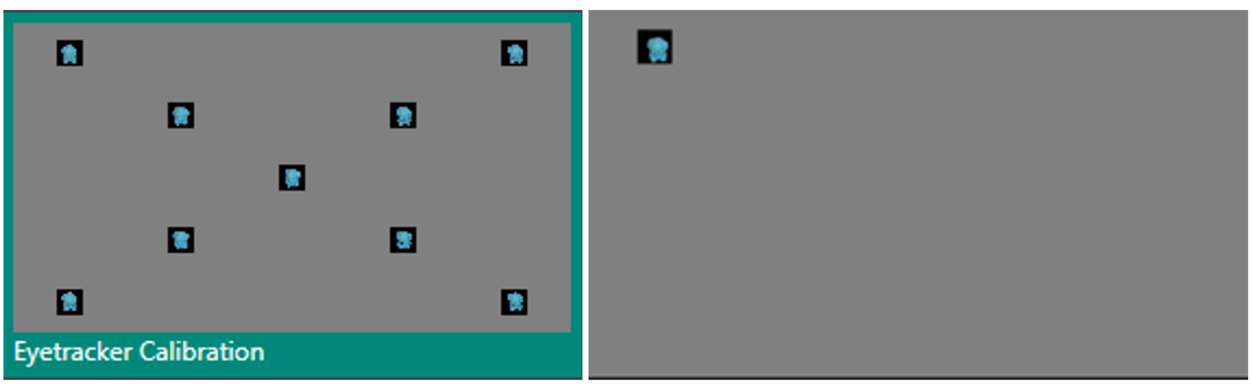

Fig. 5. The 9-point customized calibration target (right) and one point of the participant's view of the calibration target (left)

3.3.4 Contrast Sensitivity Test

All participants' CS thresholds were assessed using the standardized, web-based Freiburg vision test (FrACT) [21,22]. The FrACT is a validated test has been chosen to assess the CS threshold due to its implementability. This test can easily be administered on any computer screen, it is available through Google Chrome, and it is open source [21,22]. CS threshold was assessed using a version of the FrACT computer-based visual test battery, known as the Tumbling E task. This task consists of 24 trials of a single optotype, an image of the letter “E”, pointing in four directions (up, down, left, or right, Fig.6) to determine the “minimum visible” of each participant. Using the keyboard arrows, participants were asked to indicate the direction of the “E”, which decreases in contrast (i.e., creating a smaller difference in color between the “E” and the background) following correct answers and increases in contrast again following wrong answers. When participants could not see the direction of the “E”, they were instructed to hit an arrow key to the best of their abilities or at random, known as the “forced choice” principle [22]. The test results are provided in the form of a single metric, the LogCS, used by ophthalmologists to quantify CS [23].

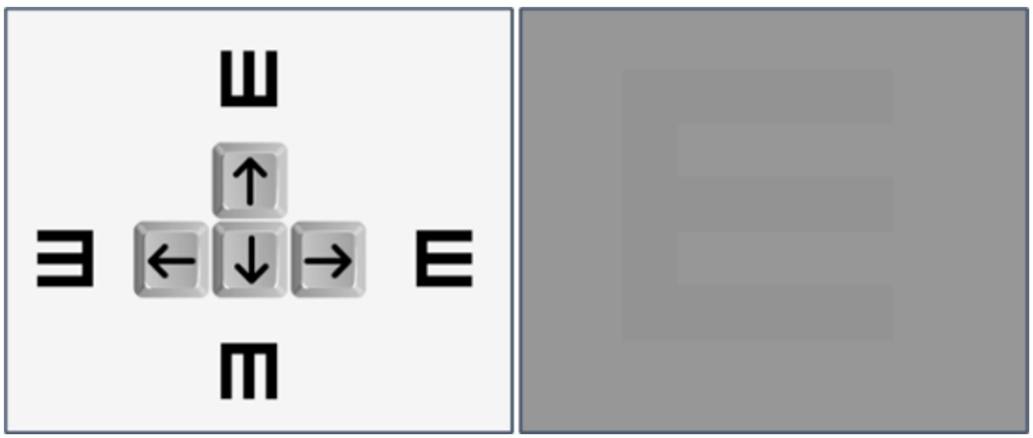

Fig. 6. Freiburg vision test (FrACT) answer choices (left), and one example of the contrast sensitivity test stimuli (right)

3.3.5 Visual Search Task

In the present study, we aim to manipulate the contrast of specific colors used on a banking website tested in a subsequent test. Object contrast is known to influence reaction time (RT) in visual search tasks [24]. Therefore, to assess RT, we developed our own version of a Spatial Configuration Search (or sometimes referred to as a “serial search task”) [41]. In the task, participants were exposed to a series of 32 images, each containing 8 x 8 rows of 64 alphanumeric symbols with one target symbol.

In these stimuli, we manipulated the alphanumeric symbol type (i.e., “4” among A’s, “2” among Z’s, “5” among S’s, and “8” among B’s, Figure 7), contrast (i.e., high and low contrast), and target position (i.e., quadrant 1, 2, 3, 4). The high contrast (10.66:1 ratio) was alphanumeric symbols of a dark gray color (#383838 [hexadecimal color]) on a light gray background (#f4f4f4), and the low contrast (1.47:1 ratio) was light gray (#cccbcb) alphanumeric symbols on the same background (#f4f4f4), which represents a contrast ratio that is below the minimum contrast ratio of 4.5:1 for text and images of text according to the WCAG 2.1 level AA success criterion 1.4.3 [25].

The 32 image stimuli were presented by a group of alphanumeric symbol types, with the contrast level being randomized. The participants were provided with examples prior to the task (Fig. 7). Before each stimulus, participants were instructed to fixate on a cross in the center of the monitor. We used the on-gaze advance function (i.e., 300ms fixation located in a predefined rectangle-shaped area of interest on the target symbol) to measure RT and to move on to the next stimuli. In cases where the eye tracking was not stable, we instructed the participants that the image should change when they find and look at the target symbol, but to say out loud when they found it if the image does not change. The moderator would then manually move on to the next stimulus and the RT would then be based on the time of participants' verbal cue which was recorded with the webcam (Fig. 8). This task was chosen because no attributes can guide the search for the target. The participant would have to search within the distractors in a random fashion [41] From this, different visual search patterns could emerge between groups, which will be analyzed in future works.

Fig. 7. Visual search task's targets position (left), example of high contrast image (middle), and example of low contrast image (right) with the target identified.

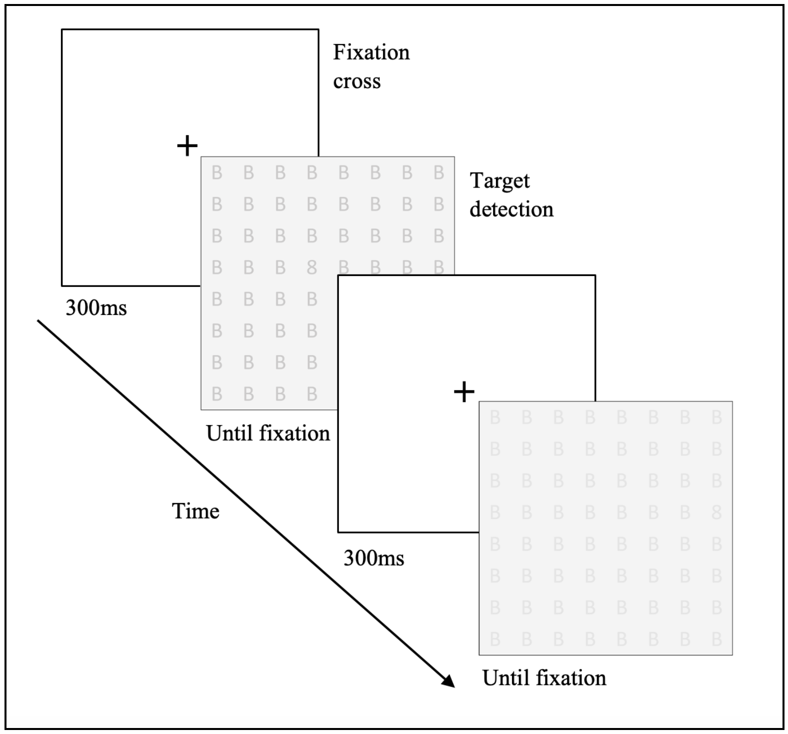

Fig. 8. Example of the sequence of the visual search task of the target number "8" showing the high contrast, and low contrast in order.

3.3.6 Visual Search Behavior

Through the use of eye tracking and the eye movement measurements (i.e., fixations and saccades), the visual search behavior was measured [26,27,28]. The calibration was successful for all participants except one participant from the low vision group and one participant from the simulation group, which were excluded from the analyses. Eye-tracking was less stable for participants in the simulation group and the low vision group, meaning that there was more data loss. This is because the glasses' frame of the simulation group and pre-existing conditions such as cataracts of the low vision group impede the ability of the eye tracker to consistently detect the pupil throughout the experiment. Consequently, 11 participants from the simulation group and two participants from the low vision group were excluded from the analysis due to data loss across the whole visual search task. For the remaining participants, the resulting variance in sampled oculometric data volumes meant that typical visual search behavioral measures such as total fixation and saccade count or total fixation and saccade time [28] could not be used.

Therefore, we used the ratio of fixation time to saccade time (i.e., fixation/saccade ratio) over the duration of a visual search task. This ratio allowed us to compare our three groups without being affected by the unequal amount of data lost between the groups during the visual search task. To calculate the ratio, we computed the sum of time of whole fixation and whole saccade captured within each image stimulus' interval. The sum of fixation time was divided by the sum of saccade time in each image, and then aggregated by contrast level for each group. An increasing fixation/saccade ratio reflects more time spent trying to process the local visual information at each fixation (i.e., fixation time) than scanning a visual stimulus (i.e., saccade time). These metrics will help us determine to compare the visual search behavior of the three groups. The literature suggests that the fixation/saccade ratio in visual search tasks increases with poorer image contrast or visibility [24], [29], or in low vision people [30,31].

3.3.7 Statistical Analysis

We performed six one-way analysis of variance (ANOVA) to assess the differences in the average CS threshold in the vision tests, as well as the average RT with low contrast and with high contrast, the average fixation/saccade ratio with low contrast and with high contrast in the visual search task, according to our three experimental groups. The one-way ANOVAs on the average CS threshold and average RT were performed with our complete sample, but our one-way ANOVAs on the average fixation/saccade ratio were performed with our participants with available oculometry data. All statistical comparisons were made using SPSS 26 (IBM, Armonk, NY, USA) with a significance threshold set at $p \leq 0.05$. Our tests of homogeneity of variance based on mean for our one-way ANOVA were all significant with a threshold set at $p \leq 0.05$, which suggests unequal variances between our group for these variables. Therefore, we ran Welch's robust test of equality of means and adjusted the p-value and F statistics accordingly. Post-hoc comparisons between groups were performed with the Games-Howell procedure.

3.4 Results

3.4.1 Contrast Sensitivity

Illustrated in Figure 3, our one-way ANOVA on the CS threshold revealed a significant main effect of group ($Fw_{(2, 17.6)} = 53.355$, $p < .001$), with simple main effects testing showing that the control group had significantly higher CS threshold (2.01 ± 0.11 logCS) than both the low vision group (1.35 ± 0.43 logCS; $p = .007$) and the simulation group (1.53 ± 0.17 logCS; $p < .001$). There was no significant difference between the simulation and the low vision groups (p =

.740). Therefore, the differences between groups are in line with our expectations, showing that the simulation affects the CS of normally sighted participants to similar levels as the low vision participants. Hence, H1 is supported (Table 4).

3.4.2 Reaction Time

For our visual search task (Fig. 9), our one-way ANOVA on the RT in high contrast showed a significant main effect of group ($Fw_{(2, 17.3)} = 20.701$, $p < .001$), with simple main effects testing revealing that the control group had significantly faster RT than both the low vision group ($p = .002$) and the simulation group ($p < .001$). We also found that the simulation group had significantly faster RT than the low vision group ($p = .015$) in high contrast stimuli. The one-way ANOVA on the RT in low contrast also showed a significant main effect of group ($Fw_{(2, 16.1)} = 15.227$, $p < .001$), with simple main effects testing revealing that the control group had significantly faster RT than both the low vision group ($p = .020$) and the simulation group ($p = < .001$). However, there was no significant difference between the simulation and the low vision groups ($p = .675$) in low contrast stimuli. The simulation affects RT for both stimuli (high and low contrast), but the effect is bigger for the low contrast stimuli and similar to low vision participants. This shows that H2 is supported for the low contrast condition but only partially for the high contrast, as there was a significant difference between the ratio of the low vision group and the simulation group (Table 4).

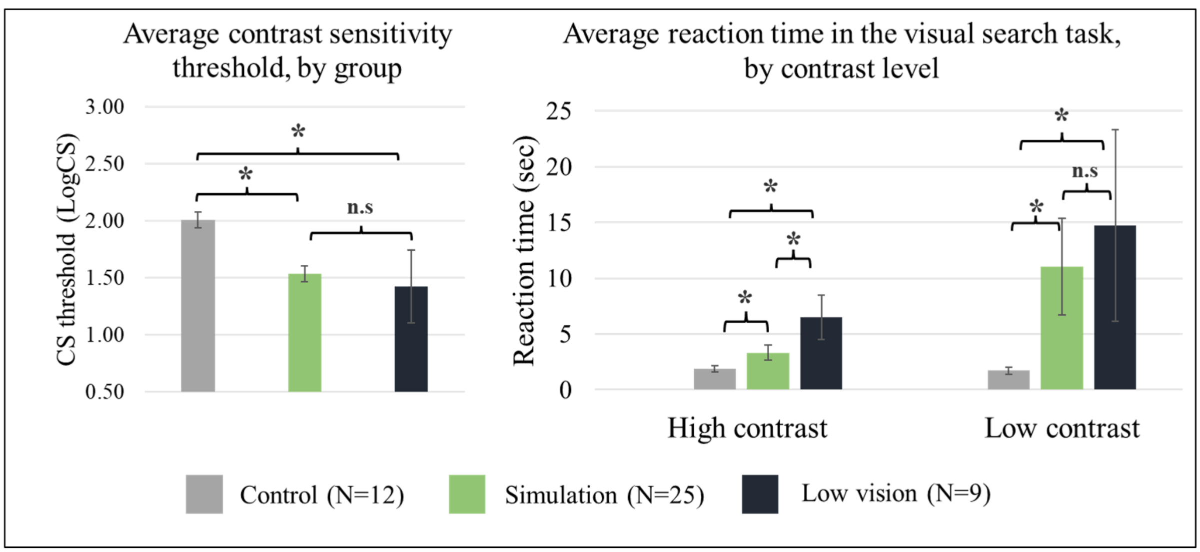

Fig. 9. Average CS threshold (left), average RT for high and low contrast level images in the visual search task (right), by experimental group. * $p < 0.05$

3.4.3 Visual Search Behavior

Lastly, for the visual search behavior (Fig. 10), our one-way ANOVA on the fixation/saccade ratio in high contrast stimuli revealed a significant main effect of group ($Fw_{(2, 10.9)} = 8.791$, $p = .005$), with simple main effects testing showing that the control group had a significantly lower fixation/saccade ratio than the low vision group ($p = .024$), but not the simulation group ($p = .078$). The difference between the simulation and low vision groups was also not significant ($p = .071$). For low contrast images, our one-way ANOVA on the fixation/saccade ratio also showed a significant main effect of group ($Fw_{(2, 10.1)} = 16.001$, $p < .001$), with simple main effects testing showing that the control group had a significantly lower fixation/saccade ratio than both the low vision group ($p = .011$) and the simulation group ($p = .008$). We found no significant difference between the simulation and low vision groups ($p = 0.445$). This shows that although the simulation had an effect on the number of fixations over the saccades, the effect was stronger for the low contrast stimuli. In the high contrast condition, the visual search behavior of the simulation was not different from the visual search behavior of normally sighted and of low vision participants. Therefore, H3 is supported for the low contrast condition but partially supported for the high contrast condition, as no significant differences were found between the simulation group and the control group (Table 4).

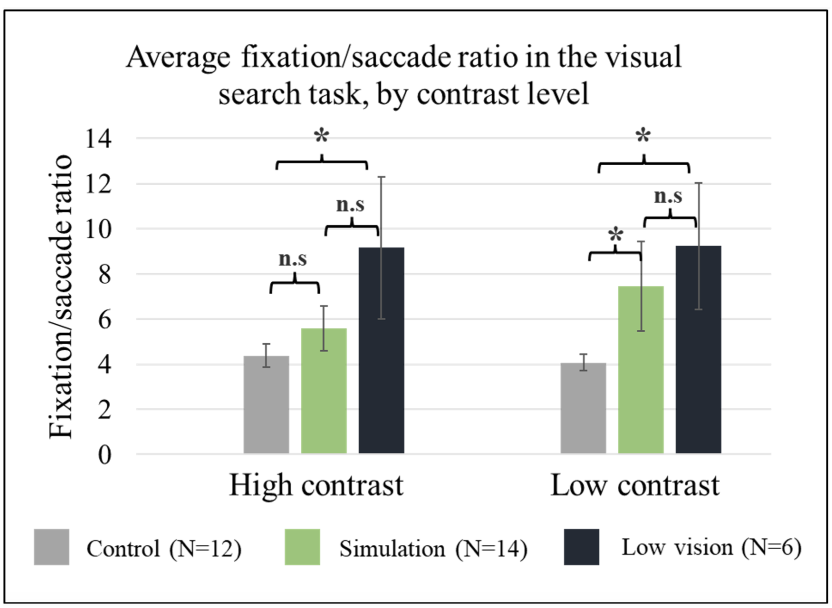

Fig. 10. Average fixation/saccade ratio over the visual search task for high and low contrast level images, by experimental group. * p < 0.05

Table 4. Summary of results grouped by hypotheses.

H	Dependent variable	Condition	Groups	Mean Difference	Standard Error	Confidence intervals (95%)	P-value	Status
H1	Contrast sensitivity (CS)	CS Threshold	Simulation < Control	-0.476	0.047	[-.591, -.362]	$p < .001$	Supported
			Simulation = Low vision	0.107	0.142	[-.291, .505]	$p = .740$	
H2	Reaction time (RT)	High contrast	Simulation < control	1.463	0.354	[.592, 2.334]	$p < .001$	Supported
		Low contrast		9.318	2.100	[4.077, 14.56]	$p < .001$	
		High contrast	Simulation = Low vision	-3.176	0.926	[-5.698, -.655]	$p = .015$	Partially supported (not supported in high contrast)
		Low contrast		-3.663	4.274	[-14.905, 7.579]	$p = .675$	
H3	Ratio of fixations / saccades	High contrast	Simulation > control	1.195	0.517	[-.117, 2.506]	$p = .078$	Partially supported (not supported in high contrast)
		Low contrast		3.380	0.936	[.927, 5.834]	$p = .008$	
		High contrast	Simulation = Low vision	-3.587	1.309	[-7.522, .348]	$p = .071$	Supported
		Low contrast		-1.792	1.427	[-5.59, 2.005]	$p = 0.445$	

3.5 Discussion

In this study, we aimed to assess whether the visual search behavior of low vision people using a computer interface can be replicated with normally sighted participants experiencing a visual disability simulation. We show that the simulation glasses were able to replicate, on average, the CS threshold of our low vision participants (H1). Additionally, the CS threshold of the low vision group had a larger deviation from the mean. This can be a result of the symptoms of the participants with low vision where 5 out of 9 reported having lower CS. In the visual search task (H2 and H3), our results show that normally sighted participants wearing disability simulation glasses demonstrate similar visual search performance and behavior to those with low vision during interactions with low-contrast stimuli, which is in line with past literature [24], [29,30,31]. The results indicate that, although the simulation glasses produce poorer vision, the simulation group retained some visual search behaviors while also adopting the behaviors of low vision participants during interactions with high contrast stimuli. The literature suggests that with lower contrast stimuli in visual search the number of fixations increases while saccades are not affected [29], and that low vision stimuli are more difficult for low vision people than high contrast ones [30]. Our findings are in line with previous literature on visual search performance in computer tasks and show that the effects of low vision can be replicated through measures of visual search behavior. However, the effect seems so be more important when the condition of the task is more difficult. Additionally, gender was controlled for by being equally distributed in each group. Regardless, there is no evidence that gender has an effect on CS [16].

These results show that the low vision simulation for mild to moderate VI is effective in replicating the behavior of mild to moderate low vision people on computer-based tasks, especially for low contrast stimuli. These findings will be helpful to better understand the way the simulation affect visual behaviors in naturalistic tasks, such as on an online banking platform. Ultimately, the goal of using the low vision simulation in a naturalistic setting is to provide helpful recommendations on an app or website through participatory user testing. By understanding the effects of low and high contrast stimuli on visual ability, we are now in a better position to understand what are the type of recommendations a participant with simulated low vision can provide, what difficulties they might encounter and why they are problematic.

This study has three main limitations. First, there was a small number of low vision participants in our sample due to the challenges of recruiting PWD [4,5]. Second, the data loss resulting from the eye tracker reduced the final sample for the visual search task, comprised of six low vision participants. Although we were able to find significant differences, and we arrived at conclusions that are in line with the literature, the smaller sample may introduce bias in our results. Third, the average age of the low vision participants is 20.68 years older than our normally sighted participants of the control and simulation groups. In fact, it is known that the visual field decreases with age, which may limit the amount of information that can be acquired within one fixation [32].

It should be noted that the LogCS was used to compare our groups and should not be used as a reference for the Cambridge Simulation Glasses, as it was not the goal of this study.

Nevertheless, our results suggest that both low vision and simulation groups may have similar visual search behavior in a computer-based information search task. This idea will be investigated in future work, where we will analyze the usability issues (e.g., WCAG 2.1 level AA success criterion 1.4.3: Minimum contrast) [25] experienced and reported by our participants in an ongoing naturalistic online banking website study. Our findings will help us better interpret the results yielded from the naturalistic tasks. These new insights will contribute to our understanding of how disability simulations can be used to replicate the behavior of people with disabilities, and consequently the usability issues experienced and identified in user test context [33,34].

Building on our findings, future research on the use of low vision simulation in could investigate the extent to which the effect of the simulation has on the ability to reading on a digital interface. As information search online is a combination of visual search and reading, future research questions could expand to naturalistic tasks and look into the differences between simulated low vision and low vision in identifying issues and issuing design recommendations related to text content.

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Chapter 4
Conclusion

The goal of this thesis was to explore the feasibility of measuring the UX of low vision simulations in participatory user testing and whether the neurophysiological measures gathered were valid. Two research questions were formulated to guide the study:

1. What are the benefits and limitations of visual disability simulation in user testing of a digital interface in accessibility research?
2. To what extent does the visual search behavior of normally sighted participants experiencing a visual disability simulation can replicate the visual search behavior of people with low vision?

4.1 Main Results

The literature review helped to identify a range of immersive low vision simulations that are available to use for UX researchers and that simulate low vision in a real-environment setting. The simulations discussed all have been tested and validated through empirical research and have all demonstrated they decrease visual ability. They also show that they have an impact on performance in certain domains to similar levels to people with low vision. Furthermore, the characteristics of the simulations have been highlighted. Their montage, frame and lens constitutes the benefits and limitations when the compatibility with neurophysiological measures used in UX is considered. As these measures tend to require access to the head and face, not all simulations are suitable for measuring the range of UX on participants wearing a simulation. Simulations that had a light frame are more likely to be compatible with EEG, emotion detection, and eye tracking as they could be modified to prevent any interference with the measures. Simulations in the form of goggles or HMDs as seen in AR had the biggest limitations. As they cover most of the head and face, the use of EEG, emotion detection and eye tracking would be considerably hindered. This literature review highlighted two key findings. First, the extension of the use of the simulations on participants in the context of user testing is promising. Second, for the measurement of UX on participants experiencing a low vision simulation, certain limitations of the neurophysiological measures can emerge such as having some compromised data all the way to not being able to record any responses.

From the review, the Cambridge Simulation Glasses, a low cost simulation that can easily be integrated in user tests conducted by organizations, was tested with an eye tracker. The results show that the simulation decreased visual ability when compared to controls, especially in low contrast conditions which is in support of our hypothesis. The participants experiencing the simulations also displayed similar search behavior to the participants with low vision which supports our hypotheses. These findings not only show the validity of the simulation, but also the ability to use it in combination with the eye tracker. Although there was some data loss potentially due to the ticker frame of the simulation, this shows to replicate visual behavior of low vision people facing potential usability issues (i.e., low contrast).

4.2 Contributions

This section highlights the theoretical and methodological contributions as well as the practical implications of this thesis.

4.2.1 Theoretical Contributions

The theoretical contributions relate to the inclusion of disability studies in accessibility research. The goal of using low vision simulations in UX research is not to replicate exactly the conditions of people with low vision but rather to gain insight into the perceptual and behavioral effects of low vision. The voices of PWD cannot and will not be replaced by the use of the simulation. The integration of PWD in this research shows that disability studies can contribute to the research on accessibility in HCI.

4.2.2 Methodological Contributions

The methodological contributions involve the use of the neurophysiological measures with the low vision simulations. This thesis provides a framework of the different features to consider when combining both. Although the findings remain to be tested, they build on the current well-researched limitations of the neurophysiological measures. Furthermore, in the case of eye tracking, it highlights the possibility for adaptations to be made for the inclusion of all participants. For example, making the calibration of the eye tracker accessible for PWD and analyzing the data in a way that can compensate for data loss due to the simulation. Such types of adaptations could be applied to other tools used in UX research.

4.2.3 Practical Implications

This thesis is expected to have practical implications for organizations who want to improve the accessibility of their web content. The simulations presented in this thesis are all available to use for conducting research. Although some might be harder to implement than others due to cost or learning how to use the simulation, they have shown to contribute to concrete, useful and implementable recommendations, more than the current and commonly used methods that evaluate the accessibility of web content. For organizations, this thesis shows that simulations can easily be integrated in their user testing, in addition the perspectives of PWD, to alleviate the drawbacks that comes with accessibility research. In fact, the Cambridge Simulation Glasses will now be included in the design cycles of Tech3lab's industrial partner involved in this UX research project as an additional way to contribute to the accessibility of their web content.

4.3 Discussion

While the use of disability simulations has been investigated in research, their involvement in HCI research and more specifically UX research has been limited. Evidence shows that low vision simulations are effective in reducing visual abilities and performance related to visual function. Simulations in participatory user testing can be useful to allow the participants to experience vision loss from a first-person perspective and to offer a controlled environment. When compared to accessibility guidelines and automatic evaluation software or even expert opinion, low vision simulations provide more relevant recommendations when evaluating the accessibility of web content. Furthermore, measuring the UX of participants undergoing a low vision simulation gives more insight in the extent to which low vision can be replicated through measures of attention, emotion, cognition and behavior.

There are two main limitations to this study. First, the search of the literature was selective. The findings gathered were not comprehensive. However, they were gathered from a large set of keywords, from interdisciplinary fields, and from backward and forward searches. Yet, important findings relating to the topics might have been missed. Second, the results from the pilot study were concluded from a small number of participants. In fact, there was data loss stemming from compatibility of the eye tracker with simulation and a lower number of PWD. Although the results are in line with the current literature, a larger number of participants would produce stronger results.

Future works should focus more on the ways the UX of participants undergoing a low vision simulation can be measured. Focusing on testing the low vision simulations in real-world UIs such as actual websites while measuring UX would help to gain insight into how much of the experiences of low vision people can the simulations replicate.

4.3.1 Final Thoughts

The rapid innovation in technology calls for rapid accessibility research in HCI. Accelerating accessibility research can be supported through simulating low vision in addition to including participants with disability. Measuring their UX is one way that helps to uncover the underlying frustrations that inaccessible ICTs can create. However, accessibility research is more than issuing recommendations for more usable web content for PWD. This is an area of research that can contribute greatly to increase the quality of life of PWD (Raja, 2016) and to promote their inclusion of this growing population in the digital world which has become integral to our society.

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Appendix A

Keywords and Synonyms List

Category	Keywords
Context	Visual Impairment Simulation, impairment simulation, disability-simulator, disability simulation, simulating disability, simulating the experiences, Web accessibility technology, Web Accessibility, Human-computer interaction, HCI, information and communication technology, ICT, accessibility, ISO
User	People/users with/without disabilities, PWD, low vision people/patients, visually impaired, vision deficient users, special needs, seniors, older adults, abled-body, designers, developpers
Artefact	Accessible Interfaces, assistive technology, adaptive interface, Adaptive Mobile Interfaces, friendly interfaces, Inclusive Interface Design, Computing Devices, graphical user interfaces, Computer-Based System, tactile technology, universal design, user centered design, information and communication technology, ICT
Simulation	Disability Simulations, capability loss simulation, artifical impairment, Immersive simulation, low vision simulation, Eye Disease Simulator, blindness simulation, simulation glasses/spectacles, priming
Tool/device	Head mounted display, wearable see-through display, Virtual/augmented reality, VR, AR, contact lenses, augmented-reality glasses, Assistive Technology, spectacles, glasses, goggles, gaze-contingent display, software, browser extension
Phase	Design Cycle, Designing, Evaluation, design workflow, software development, Evaluation
Disability and Impairment	color-Blind, Tunnel Vision, achromatic vision, Low Vision, blind, Macular Degeneration, Age-related macular degeneration, AMD, reduced vision, prosthetic vision, comorbidities, cataract, diabetic retinopathy, glaucoma, partial, blindness, blurry vision, double vision, cataract, vision loss, visual impairment, central vision, peripheral vision, light sensitivity, scotoma, Visual impairment, visual disability, visual disorder, Low vision, retinal disparity, optical defocus, posterior visual impairment, lens, retina, degenerative, progressive,
Attribute	Usability, accessibility, Usability Problems, Usability Evaluation, user/usability testing
Objective	Challenges, consequences, Opportunities, accessibility limitations, influences, Understanding, Empathy, awareness, education, Daily living, universal access, human-centered, inclusive

Appendix B

Characteristics of the Analog Simulation Kits

Kits	Low Vision Symptoms / Visual Impairment	Quantity	Price	Articles
Cambridge Simulation Glasses	Mild vision loss (acuity and contrast sensitivity loss; VA: 1 pair: 20/24, 2 pairs: 20/40, 3 pairs: 20/60, 4 pairs: 20/110, 6 pairs: 20/400)	1 (x5)	£90 for pack 50 (£29 for 5)	Allen et al., 2018 Angeleska et al., 2020 Clarkson et al., 2011 Dos Reis et al., 2020 Goodman-Deane et al., 2013 Rae et al., 2016 Stalin et al., 2021 Zallio et al., 2021 Xiong et al., 2020
Good-Lite (Visualeyes Vision) **Simulation Glasses**	Combination loss Central loss Peripheral loss Overall blur Hemifield/hemaniopia Low contrast Color (low cataract)	7	$22.95 for all ($4.95 each)	Marrington et al., 2008 See, et al. 2010
Sim Specs	Horizontal Diplopia Developing Cataract Birdshot Uveitis Tunnel Vision Severe vision los Right side loss Retina degeneration Reduced visual acuity Loss of visual acuity Binocular vision loss Hazy vision	10	£280 (£29.40 each)	Juniat, et al., 2019 Rae et al., 2016

Fork in the Road	Central scotoma (VA: 6/120 and 6/60) Tunnel vision (VF: 10° and 20°) Diabetic retinopathy (VA: 6/30) Blur/glare (VA: 6/24, 6/60, 6/120 and 6/240) Right and Left hemianopsia (VA: 6/60) Right and Left homonymous hemianopsia (VA: 6/60)	13	$487 for all (between $33 and $44 each)	Anand et al., 2003 Copolillo et al., 2017 Heasley et al., 2004 Stark et al., 2020 Rousek et al., 2009 Rousek et al., 2011a Rousek et al., 2011b
Zimmerman Low Vision Simulation Kit	Visual acuity (VA: 20/70 [6/20]), 20/200 [6/60], 20/500 [6/150], and 20/800 [6/240]) Peripheral field loss simulations (VF: 3°, 7° and 10°) Macular degeneration (near and distance viewing) Cataract Scotoma Hemianopsia Blindness	11	$375	Hollo et al., 2021 Bozeman, 1998 O'Brien et al., 2014 Bradley, 2020 Hegde et al., 2018

Appendix C

Characteristics of the Augmented Reality Head-Mounted Displays

Hardware	Software	Low Vision Symptoms / Visual Impairment	Studies
Oculus Rift HMD - PlayStation 4 Camera (85◦ field of view, 1280x800 feed at 60 fps).	SIMVIZ	Macular degeneration Diabetic retinopathy Cataract Glaucoma Color blindness Diplopia	Ates et al., 2015
HTC Vive Headset - ZEDmini stereoscopic cameras - Tobii eye-tracking	OpenVisSim	Glaucoma	Jones et al., 2020
Samsung Gear VR - Vuforia's camera see-through mode on the Samsung Galaxy Note 4 - Head tracking	Empath-D (prototype)	Cataract	Choo et al., 2017