Exploring the Role of Tunnel Vision Simulation in the Design Cycle of Accessible Interfaces

Rie Kamikubo
The University of Tokyo
Tokyo, Japan
rkamikub@iis.u-tokyo.ac.jp

Keita Higuchi
The University of Tokyo
Tokyo, Japan
khiguchi@iis.u-tokyo.ac.jp

Ryo Yonetani
The University of Tokyo
Tokyo, Japan
yonetani@iis.u-tokyo.ac.jp

Hideki Koike
Tokyo Institute of Technology
Tokyo, Japan
koike@cs.titech.ac.jp

Yoichi Sato
The University of Tokyo
Tokyo, Japan
ysato@iis.u-tokyo.ac.jp

ABSTRACT

Despite the emphasis of involving users with disabilities in the development of accessible interfaces, user trials come with high costs and effort. Particularly considering the diverse range of abilities such as in the case of low vision, simulating the effect of an impairment on interaction with an interface has been approached. As a starting point to assess the role of simulation in the design cycle, this research focuses on allowing sighted individuals to experience the interface under tunnel vision using gaze-contingent simulation. We investigated its implementation reliability through the analysis of empirical tests of prototypes compared between participants under simulation and intended groups. We found that the simulation-based approach can enable developers to not only examine problems in interfaces but also be exposed to user feedback from simulated user trials with necessary evaluation measures. We discussed how the approach can complement accessibility qualities associated with user involvement at different development phases.

Keywords

Accessible Design; Simulation; Low Vision; Design Process.

1. INTRODUCTION

People with visual impairments have difficulty in seeing in a variety of ways, from mild to severe conditions of "low vision" to no vision at all. Nearly 246 million people worldwide have low vision [23], and the individual may experience limited peripheral or central vision, or tunnel vision, as well as poor visual acuity or light sensitivity [7]. Regarding such visual adversity, technology is expected to bring the user experience to many aspects of their lives. For example, accessibility software such as ZoomText [29] is frequently used among computer users with low vision to modify the design of standard interfaces to match their functional needs [30]. However, some studies have examined that even proficient technology low vision users struggled to perform computer tasks because the tools were designed difficult to use and inefficient [30, 34].

In theory, inclusion of users as portrayed in "User Centered" or "Participatory" design approaches should encourage the development towards accessible solutions [16, 28]. Developers are encouraged to obtain continual user feedback throughout the design cycle to repeatedly test and refine their prototypes with the users [26]. Despite its emphasis, active involvement of users with low vision is yet significantly difficult to practice. According to [27], the diverse range of abilities complicates finding representative participants for user trials or having controlled evaluation experiments. This can also provide practical challenges in obtaining subjective inputs or objective data from the users to explore design requirements [21]. In addition, many developers are not fully aware of much greater variety of user characteristics and functionality [22].

To supplement incorporating the perspective of the users with low vision, simulation techniques have been approached to visualize or experience possible interaction patterns caused by particular disabilities. For example, predicted models [2, 3, 8] or low-tech simulation glasses [12] are intended to support designers to get a sense of how a person with a visual disability would experience the interface. However, such disability simulation tools have been seen to build empathy with users with capability loss [9, 12, 13]. In order for the designers to consider the practical aspects of the simulation-based approach, it is important to provide a better image of its role within the framework of designing and evaluating prototypes for accessible solutions.

As a starting point to assess how visual impairment simulation can bring the potential sources of reliance for the developers, we propose to conduct *a full design cycle with the simulation-based approach* in the development of accessible interfaces. We began with a preliminary user study with

W4A '18, April 23–25, 2018, Lyon, France

ISBN 978-1-4503-5651-0/18/04…$15.00

DOI: https://doi.org/10.1145/3192714.3192822

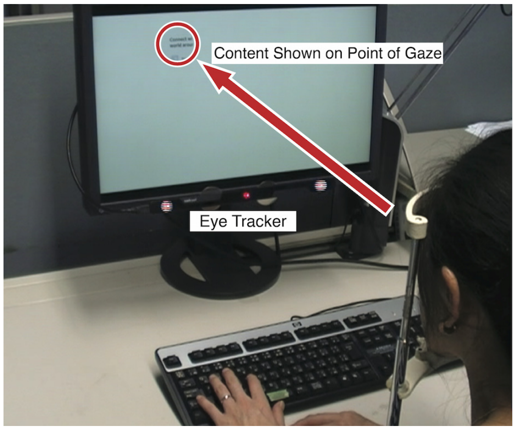


Figure 1: Sighted participant seeing a web page under a simulated tunnel field of view which is contingent on real-time gaze direction. An eye tracking device is positioned on the bottom of the 22” monitor.

low vision participants to define initial requirements of web access concerning limited peripheral vision. We reflected the use of gaze-contingent simulation of visual limitations [24] in proceeding the design and evaluation of prototypes for our designed experience. In this work, the simulator emulates “tunnel vision” to represent limited peripheral vision such as that found in Retinitis Pigmentosa (RP) [22] or glaucoma [36] (Shown in Figure 1). Even though we specifically focus on a certain visual impairment, we aim to pave the way for our simulation technique to meet the following two objectives: developers can 1) quickly observe the effects of prototypes under a simulated visual condition and 2) recruit sighted participants for representative user trials to gain simulated user feedback.

To the best of our knowledge, our work is the first to investigate the expected benefits of simulation applied in the development contexts of gathering feedback and learning from the prototypes and users. We performed a series of empirical studies to unravel how the tunnel vision simulation can facilitate capturing design and evaluation input on the prototypes from sighted participants, in comparison to evaluation data from the RP users. Also, as a baseline validation study, we examined that the simulated condition was able to impact saccadic eye movements of the sighted participants in a way that resembled the gaze behaviors of RP-diagnosed participants (with peripheral visual field loss) [18]. Importantly, as we analyzed our empirical-study results between the two groups, we assessed how the simulation-based approach served to meet the following qualities of design and evaluation:

- Simulation would support user inputs regarding elementary UI and usability issues of design alternatives by allowing representative user trials under controlled conditions. Survey results for choice and preference of possible interface designs by sighted individuals under simulation corresponded with the results by RP participants.

- Simulation would support the design of research against user performance criteria as a way to determine whether to continue with or discard the designed experience or interaction. Verifying UX objectives with studies by sighted participants under simulation unraveled the necessary human factors which were also observed by RP participants.

Based on the empirical studies comparing findings of simulated tests with those of tests with intended low vision users, we discuss a series of design implications in incorporating the simulation-based approach. Simulation is not used to completely replace the procedure to work with representative participants. It has the potential value in providing developers with a tool that can ease observing the interaction between the users and prototypes. While emphasizing users with the widest range of abilities in the design process is always important for accessible design, we aim to facilitate the designers in determining the application of simulation techniques to fit their style and work and enhance the approach in developing accessible solutions.

2. BACKGROUND AND RELATED WORK

Some variations of User Centered Design specifically advocate constant communication between designers and users with disabilities [17, 21, 37]. However, in addition to time and budget constraints, designers are prevented to adequately involve or understand users with diverse abilities. In the case for low vision, even from the same disease such as Retinitis Pigmentosa (RP), the progression of constricted visual fields varies among individuals [6] and these characteristics complicate the design of necessary requirements and its evaluation. Though having controlled groups is important to observe the effects of multiple prototypes, the designers are accustomed to working with a small number of participants or the longitudinal studies [27].

An extensive range of tools has been proposed to assist the designers to understand the end user requirements, which include guidelines, self-observation designer trials, and simulation apparatus [40]. For example, a series of Web Content Accessibility Guidelines are for web designers to check if their websites are appropriate for a wide range of user communities. Conversely, such an afterthought is not adequate in considering accessibility within the design process [28]. In addition, observation methods such as heuristic evaluation of usability are often emphasized in User Centered Design and rapid prototyping [26]. However, developers often assume an audience without disabilities or approach accessibility issues as “someone else’s job” [28]. Lastly, research and development of physical or digital simulation tools have been showcased to inspect possible interaction patterns caused by particular impairments [5].

According to [14], there are two principal approaches in the use of simulation. One is to gain insight into the difficulties faced by potential users and understand their challenging scenarios with existing interfaces or products [9, 12, 13]. Low vision simulation of gaze behaviors [24, 35] can also provide a brief of experience of visual capability loss. The second approach is for evaluation of designs, which serves a much better purpose than the first approach which is intended to ideally inspire creative solutions. Simulation is generally acknowledged to review some design flaws by seeing the effect of the simulated impairment [2, 3, 11]. Automatic annotation of inaccessible points of the web pages is also available [31, 33]. In addition, the authors from [5] validated the effectiveness of simulation in identifying usability problems. Moreover, various human models based on perceptive or cognitive architectures have enabled automatic evaluation of interfaces via estimated task completion time [1, 3].

While the second approach is promising, it is important to assess how simulation can facilitate incorporating the perspective and feedback of users with disabilities in proceeding the design process for accessible solutions. Many attempts have showcased the simulation tools to supplement the component of evaluation and construction of empathy towards users but with few practical applications investigated.

3. EXPLORING ROLE OF SIMULATION IN DESIGN CYCLE

Our research proposes to explore the role of simulation in a design cycle to identify how the simulation-based approach functions and reflects in the human-centric development that leads to accessible solutions. We exclusively focus our development of technologies to target low vision users which vary in multiple forms of impairments and come with difficulties in involving them throughout the design-evaluation process. There are three phases that proceed to bring about the role of simulation in the design cycle:

Phase 1 involves the very beginning stage of user study with low vision individuals when there has not been clear target audience nor discrete concept. The aim is to determine target user needs and problems.

Phase 2 involves the implementation of necessary low vision simulation that suffices the development for the intended audience. This phase also involves validation of the simulation effect to be used by sighted individuals to confirm its implementation.

Phase 3 involves design trials beginning with the generation of the concept via early prototyping. The proposed conceptual design will serve the base in the series of empirical studies for investigating how our simulation complements the practice of gathering feedback in user trials.

The results of the simulation tests with sighted participants are compared with the actual trials by the intended user groups to address the potential sources of benefit of simulation in the design cycle.

3.1 Phase 1: User Study

As a first step to conceptualize our development focus, we conducted semi-structured interviews and observations of web browsing tasks with 5 low vision participants (3 female, 2 male) for requirements gathering. We uncovered their tasks and goals on computer and web access, and revealed user needs associated with visual field defects. They were all computer class students at the local job training facility for the visually impaired, and their age ranged from early-twenties to early-sixties. Three were diagnosed as RP, with each had varying levels of reduced peripheral vision. For user observation, we assigned them with visual search tasks to find a specific piece of information on a website of the facility using their computers with familiar assistive tools.

3.1.1 Findings

We found that reduced peripheral vision was the critical element in hindering web access and limiting the performance of scanning a web page. While problems do exist in identifying target location under peripheral visual field loss [36], the participants with visual field defects faced challenges in locating important parts across the page to gain its whole picture. They reported the experience as "stressful," as the field of view of the RP participants ranged from 10 to 20 degrees, while the two also had partial color blindness and cataract conditions. Also, as observed in the work from [34] and [30], the participants struggled to get an overview of a web page due to the limited view caused by commonly-used accessibility tools such as screen magnifiers. They often explored wrong links to different pages. The underlying needs of low vision users were also observed as they tried to fully utilize their remaining vision as possible even though screen readers were available. The participant asserted that: *"I prefer to see with my eyes if I want to accurately perceive the information."*

3.1.2 Design Criteria

Taking into consideration of user needs and problems based on the study findings, we focused to develop accessible solutions to guide efficient scanning of web page content. Our conceptual design was proceeded with navigation aids for users with reduced peripheral vision to visually locate the important regions which are found to play vital roles in gaining the whole picture of the page [38]. Simulation would come into play considering extensive difficulties in involving these users throughout the design cycle and performing representative user trials. We move to Phase 2 to generate necessary visual impairment simulation to reflect and investigate the approach for exploring various prototypes in our empirical studies.

3.2 Phase 2: Implementing Simulation with Validation Study

As we determined our intended low vision user groups and formed our initial design focus, we integrated the gaze-contingent visual impairment simulation [24]. This is an effective means to see the effect of reduced peripheral vision on interaction with an interface. Since peripheral visual field loss varies in degrees, we specifically encouraged to simulate "tunnel vision" as a controlled form of reduced peripheral vision. Our simulator functions by estimating the gaze of a person on a display screen and outputs the displayed content at a 5-degree visual angle which is updated continuously in real time. We approached accurate emulation of visual field area by positioning the eye tracking device, Tobii EyeX Controller [1], on the monitor 60cm away from the user whose head was stabilized on a chin rest. This size of the area

---

[1] http://www.tobii.com/xperience/products/

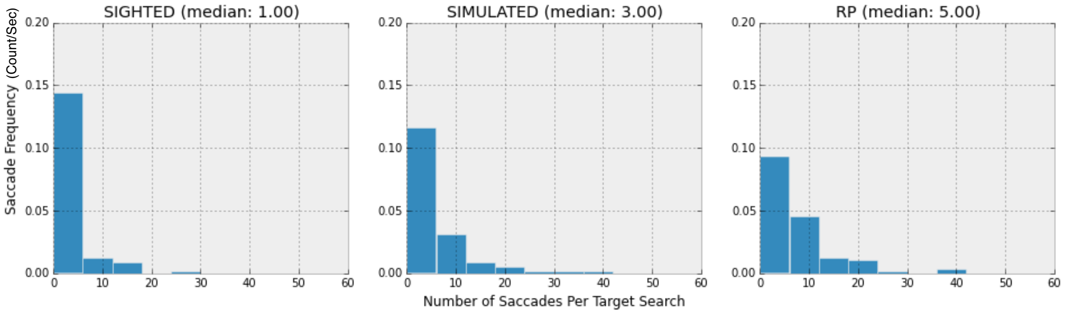


Figure 2: Frequency distributions of saccade counts examined from the eye movement validation study under three conditions, sighted, simulated tunnel vision, and low vision with RP. Average count per target search is presented at the top of every normalized histogram. Counts are 1 for sighted, 3 for simulated tunnel vision, and 5 for RP.

technically corresponds to how the field of view is restricted to central vision because rod cells used for carrying out peripheral vision are vastly lost within the five degrees of visual angle [39]. Before employing and assessing the simulation approach in the prototyping and testing stages, we conducted a study to validate whether our simulator appropriately elicited similar gaze patterns of sighted individuals as those observed under reduced peripheral vision of RP individuals.

3.2.1 Validation Study Method

We collected gaze positions during visual-search experimental trials from the three groups, sighted, simulated tunnel vision, and RP with 6 participants involved in each condition. According to [18], participants with tunnel vision frequently make saccadic eye movements that exceed outside their visual fields. We then computed a number of saccades that exceeds 5 degree visual angle representing the size of the tunnel visual field. We hypothesized that the saccade frequency should increase under limited peripheral visual field conditions.

For each condition, the common protocol was that the participants were instructed to freely view a webpage image with the goal of identifying the location of a target content region. This task was conducted with a total of 4 different images per participant, and each image came with 5 search targets visually specified to the participants prior to every search trial. Once they had located the target, they were asked to press a F key while fixated at the target which initiated the next trial. No time constraint was enforced over the tasks. We ran a calibration program at the start of each image session, and the order of images were randomly presented using Latin squares [15]. The raw eye positions were recorded during the course of sequential search trials and were imported as a series of x, y screen coordinates.

3.2.2 Findings

Our study analyzed 120 gaze patterns (data from 6 participants x 4 images x 5 targets) in deciphering whether the simulator affected sighted individuals on their scan patterns. We validated that the simulated tunnel-vision and RP behaviors of gaze patterns appeared to be more consistent than what were observed with sighted and RP. We generated normalized histograms of saccade frames (Figure 2) based on the number of saccades made outside the 5-degree visual fields in gaze shifts between the fixated areas. From the Chi-squared distance measured to compare the histograms, the value for distance was greater between sighted and RP histograms ($d = 18.26$) than the value in a pair of simulated and RP histograms ($d = 5.76$). Statistically, there was not a significant difference when comparing simulated tunnel-vision and RP conditions ($p = .218$, chi-square test). On the other hand, we found a statistical difference between sighted and RP conditions ($p = .001$).

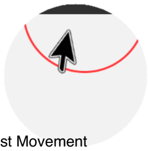
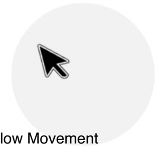
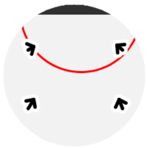
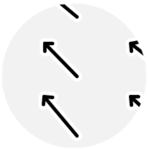
To discuss the characteristics of scanpath behaviors observed, the participants from simulated tunnel-vision and RP conditions made large eye travels to compensate for the lack of of spatial understanding of the webpage layout. Due to the small field of view, they had to move their gaze more frequently outside of their visual field across a web page to make an effort to understand the general picture. In contrast, the sighted participants can comprehend the overall layout of regular visual interfaces almost instantaneously, in which large and frequent saccadic movements are not necessary to scan the page.

3.3 Phase 3: Designing

Our design for the navigation aid involves accessible visual markers that can offer direction and distance information in reaching important regions across a web page to perceive the big picture of a website. As shown in Table 1, we came up with five initial prototypes to address possible accessible interfaces. We denote the regions as brand logos, navigation bars, headings and sub-headings, or pictures on the page. As prior work in detecting salient parts of web pages has utilized collective web-viewing gaze data [4] or crowd-sourced landmarks [10] from sighted users, we focus on the design elements of the navigation aid where the regions to scan are predefined. In terms of the navigational features, the prototypes are broken into two categories addressing relative and absolute frames of reference in offering navigation cues [20].

To allow for optimized guidance relative to where on the page the users are currently looking, we propose to provide route instructions via gaze-controlled visual markers (labeled as RA, RL, RI). We estimate where on the page

Table 1: Prototypes seen at the current gaze location under simulated tunnel vision with respect to the target region (indicated by a red circle).

Navigation ID	Close to Target	Far from Target
RA	 Fast Movement	 Slow Movement
RL		
RI		
AL		
AA		

the users are currently looking and display the navigation aid over the remaining visual field. We assume the following prototypes would reduce the perceptual challenges in detecting and tracking visual feedback under limited vision in the periphery.

- RA (Relative Arrow) points the direction towards the target region. Distance is represented by its motion which becomes faster as it gets close to the target and slower as it gets further away.
- RL (Relative Line) shown like a compass stick shifts its direction towards the target. How far away from the target is visualized by the thickness of the stick: the further away, the thicker it gets.
- RI (Relative Inverted) shows the gaze-estimated region in inverted colors for enhanced contrast. Direction as well as distance are indicated by the amount of inverted-color region shifted towards the target. As the visual field gets closer to the target region, the inverted color display is represented close to a 360 degree circle, and the angle gets less (visualized more like an arc) as the visual field gets far away from the target.

To investigate the user experience of utilizing absolute navigation cues, we present visual markers (labled AL, AA) that provide global direction and distance information that do not change regardless of the currently viewing region. The route instructions are centered around target regions and are displayed over the whole window of web content.

- AL (Absolute Lines) has a radial design where lines branch out starting from the target region in a circular way. Tracking the lines can lead the user's vision to reach the target. The lines become densely packed near the target and sparse when far from the target.
- AA (Absolute Arrows) has a vector field design which displays a collection of arrows with a given magnitude and direction depending on the location of the target.

Starting from the next section, the prototypes are tested with simulated tunnel vision participants to assess the use of simulation starting from the early design stages. The results from the empirical studies are analyzed and compared with those performed by low vision users diagnosed with RP.

4. USABILITY TESTING

We conducted usability testing to check how simulated users would react to the "look and feel" of our five prototypes in comparison to that of actual users with disabilities. We set up two different groups of participants (Test 1: 12 sighted individuals under simulated tunnel vision, Test 2: 6 RP individuals with limited peripheral vision) for the user trials. We collected insights into necessary feature implementations for visual-search tasks and which interface alternative was preferred for task performance.

We evaluated the use of five different navigation markers, and Table 2 presents the prototypes in order of ranking based on average rating scores received for each evaluation metric from both trials. Since the simulated study allowed for controlled test conditions, the Wilcoxon signed-ranks test was run to define statistical significance when comparing the prototype conditions in Test 1 (Shown in Table 3). Regarding visual differences of the RP participants and the small group size, it would be difficult to run statistical evaluation. For Test 2, both subjective inputs and objective data were taken.

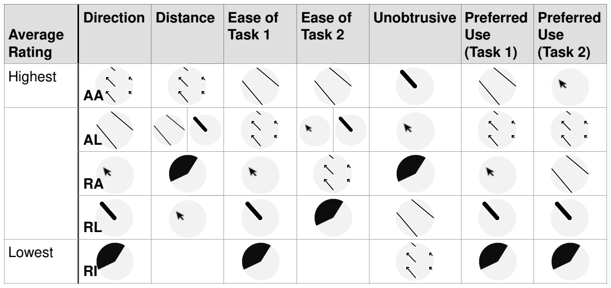
4.1 Method

The participants were instructed to indicate the location of targets on a display screen for visual-search tasks as similarly given in the eye movement validation study. There was a total of five sessions, and each session was performed under one of the five prototype conditions to evaluate the interfaces for navigation to targets. The visual markers (i.e. prototypes) were displayed on the screen once the participants pressed a SPACE key. The Latin square was used to counterbalance the order of the prototype presentation to reduce learning or fatigue effects [15].

The simulated tunnel vision participants (9 male, 3 female) were assigned with two sets of tasks for each experimental condition. Task 1 was to find 5 target dots displayed sequentially over a white screen. Task 2 included searching for 5 target regions over a webpage image. On the other hand, we ran only Task 2 for the RP participants (3 female,

Table 2: Rankings of prototypes. The order is based on average UI rating scores, with the highest rated prototype shown on top.

(a) From Test 1: simulated tunnel-vision



(b) From Test 2: RP vision

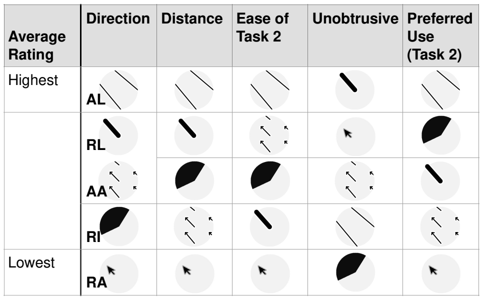


Table 3: Summary of results from Wilcoxon signed-ranks tests on simulated tunnel-vision participants in usability testing. The prototype conditions (row header) were analyzed in terms of evaluation measures (column header). The color opacity reflects its level of significance, likewise noted by “**”($p \le .01$), “*” ($p \le .05$), & “†” ($p \le .10$)

	Direction	Distance	Ease of Task		Unobtrusive	Preferred Use	
Task	1	1	1	2	2	1	2
Nav. ID							
RA / RL	.13	.04*	.85	1.00	.39	1.00	.23
RA / RI	.02*	.39	.08†	.01**	.04*	.50	.06†
RA / AL	.85	.04*	.21	.66	.20	.23	.55
RA / AA	.41	.04*	.48	.10	.05*	.58	.63
RL / RI	.46	.08†	.27	.05*	.03*	.64	.69
RL / AL	.23	.82	.10†	.42	.03*	.19	.84
RL / AA	.04*	.90	.45	.40	.06†	.64	.55
RI / AL	.02*	.10†	.03*	.03*	.93	.09†	.41
RI / AA	.01**	.04*	.05*	.22	.59	.38	.38
AL / AA	.24	.92	.30	.21	1.00	.24	.78

3 male). Due to the varying degrees of visual defects and expected eye fatigue, investigating the tasks under two different background screens for the influence on UI attributes was impracticable. At the end of every stage, the participants were asked to answer rating questions regarding their task done on a scale of 1 to 6 with no middle rating, though the questions vary slightly between the two tests. After finishing all of the sessions, the participants ranked the five prototypes. We launched the calibration program in prior to the task per stage.

4.2 Evaluation Metrics

We measured important aspects of usability with how each prototype looked to the participants and how they felt using them to complete the assigned tasks. We asked the participants to rate the ease of following navigation information in terms of the visualized *direction* and *distance* (6 = very easy, 1 = very difficult). We also asked whether the appearance of the markers were affecting the legibility of web content (6 = unobtrusive, 1 = obtrusive). Moreover, we questioned to rate the *ease of task* completion and rank prototypes in order of *preference* (with 6 being most likely to use again to complete search tasks). For the RP participants, we made sure to verbally ask to rate the usability attributes and followed up with subjective feedback of their rating scores.

4.3 Evaluation Results

We observed AL receiving high ratings in both tests for the ease of understanding *direction* and *distance* information. Statistical significance was revealed from RI/AL (p = .02) for *direction* and RA/AL (p = .04) for *distance*. There was a significant tendency in RI/AL (p = .10) for *direction* as well. The RP participants also reported AL to be easy to visually follow navigation instructions. AL was rated highest on average for both *direction* and *distance*.

In terms of the *ease of task* completion, AL was labeled in the positive range by 5 RP participants and received the highest average score by the simulated participants as well. There was a statistical significance in RI/AL (p = .03) for both Task 1 and 2 and a significant tendency in RL/AL (p = .10) for Task 1. In the prototype ranking for *preference*, AL received the highest score from both simulated (for Task 1) and RP participants, not to mention the result can be brought upon high ratings in *direction*, *distance*, and *ease of task*. Four RP participants selected AL as the most preferred condition to complete the task.

Even though statistical significance was found with AA in terms of *direction* (RI/AA p = .01; RL/AA p = .04) and *distance* (RI/AA; RA/AA p = .04), we could observe a trend that the majority of the simulated participants favored AL for the overall performance in terms of *ease of task* and *preference* results. Similarly, this corresponded with how RP participants perceived AL compared to AA. Many of the participants reported the arrows of varying sizes to be complicated in design and not intuitive in tracking navigation information.

For the *unobtrusive* quality during search on the Web, both test groups labeled RL and RA as the top two in the ranking. RA was significantly higher than AA (p = .05), and RL was significantly higher than AL (p = .03) and showed a significant tendency over AA (p = .06). We observed a possible trend for RA and RL to be visibly non-distracting compared to AL and AA.

We collected similar subjective feedback between the two groups regarding relative navigation interfaces influenced by poor calibration accuracy. Simulated participants reported the offset between the location of the gaze-based marker and the point of their focus on the screen. RP participants also mentioned that it disappears from their visual field. The mean accuracy of the total of 11 simulated participants was 1.54 degree of visual angle with the standard deviation of 1.35. For the 6 RP participants, it was 2.95 degree with the standard deviation of 1.7. The level of accuracy was different among fixations at different parts of the screen. Interestingly, such interaction caused sighted participants to articulate the jittery movement of the markers which was not perceived by the RP participants.

We obtained contradicting evaluation results for RA, in which it received the lowest *preference* by the RP participants. They reported it to be difficult to detect even though it was rated as visibly non-distracting. On the other hand, RA was most preferred for search tasks over web images by the simulated participants. We found a tendency in statistical significance for RA over RI (p = .06) for *preference* in Task 2. To articulate another contradicting evaluation, the simulated participants gave the low UI rating against RI, whereas it received the second best *preferred use* for the RP participants to complete the task. Regarding RI for the *ease of task* completion in Task 2, there was a statistical significance with RA (p = .01), RL (p = .05), and AL (p = .03). In the prototype ranking for *preference* to perform Task 1, AL showed a significant tendency over RI (p = .09). However, one RP participant reported that *"I can reach the target with the lines (i.e. AL) but I can't see what is there."*

4.4 Discussion

As a prototyping technique, the simulated study with sighted participants addressed interface problems in search task experiences, which were analogous to the evaluation results from RP participants. We were thus able to explore design alternatives before deciding which one to carry forward to the next stage. To guide the limited peripheral vision to locate target content, the absolute prototype AL was favored the most by both test groups for overall user experience. Even though visual abilities still vary between the groups, we could see that the versatile indication of directions and distance offered by relative interfaces required more perceptual effort than static absolute interfaces. Along with calibration accuracy, they mentioned the trouble of constantly tracking the visual instructions from the gaze-based relative interfaces.

Visibility differences between the test groups still posed challenges in investigating necessary visual design. For simulated participants, RA and RL were visually noticeable and considered not interfering with web content visibility. For RP participants, the simple graphic design of RA and RL was not detectable under poor acuity or clarity. RI was preferred when it empowered the RP participants to see the content better. Having the focus region to be visibly enhanced facilitated content understanding. With their standard visual sensitivity, the simulated participants did not find it easy to process visual information from RI.

5. USER TESTING

To further investigate our simulated user research to be effective as part of the design cycle, it is important to decipher user experience aspects of the navigation aid in assisting scanning of web pages. We again performed two trials, one with 12 sighted participants (8 male, 4 female) and the other with 6 RP participants (including 3 members from the prior usability testing; 4 female, 2 male). We asked them to complete online shopping tasks and evaluate the experience of using the top-rated navigation marker AL from the prior study. We aimed to grasp rich and interactive user feedback based on measurement against performance criteria.

5.1 Method

The participants were asked to complete two sets of shopping tasks per condition (with and without an option to use the navigation aid). These interactive search tasks were inspired by the work from [32]. Searching and selecting an item of interest from the list or adding it to favorites were included in the tasks. We held tutorial and practice sessions on one website prior to testing with two other websites for each condition. Activating the navigation aid with a SPACE key would guide the users to representative elements of web pages. Five representative regions were preselected and available per page such as a navigation bar, a section for recommended items, or a cart button. The participants could sequentially search for these regions. The order of given websites were randomly selected.

The only difference in the study with the RP participants from the simulated evaluation was that we added the feature to zoom in on the region around the estimated gaze point. We also incorporated the Wizard-of-Oz method [19] to simulate speech output by a human for the content where their gaze is focused. We had to make sure the participants were able to 'see' the content to examine the usability attributes of our prototype.

At the end of the experiment, the participants were asked to answer rating questions on the usability attributes. They rated these attributes in a scale of 1 to 6 (with 6 representing higher usability) under each condition of the navigation aid options. We followed with interviews for in-depth analysis of the results. Both quantitative and qualitative measurement were considered in the studies.

5.2 Evaluation Metrics

The participants evaluated content scanning aspects in online shopping experiences regarding *layout*, *overview*, and *spatial context* comprehension, and *ease of search* for relevant information. Even though we run the interactive search tasks twice for each website, the participants were asked to reflect their completion of the second task on the rating of usability aspects. We performed this measurement to see how completing the first task (either with or without the aid) influenced the scanning experience in the second session on the same website. The level of spatial contextual awareness and quality for search performance in the second task are assumed to correlate with the comprehension level of layout of page elements and overview of the content acquired from the first task. We statistically evaluated the results from the simulated study.

5.3 Evaluation Results

We explored the use of the navigation aid to investigate trends, similarities and differences in evaluation results between the simulated (Test 1) and RP groups (Test 2). As shown in Table 4, we compared the two conditions of online shopping experiences, with and without the navigation aid, by running the Wilcoxon signed-ranks test for Test 1.

Table 4: Summary of results from Wilcoxon signed-ranks tests on simulated tunnel-vision participants in user testing. The conditions of with and without the navigation aid (row header) were analyzed in terms of evaluation measures (column header). The color opacity reflects its level of significance, likewise noted by "**"($p \leq .01$), "*" ($p \leq .05$), & "†" ($p \leq .10$)

	Layout		Overview		Search		Spatial Context	
	p	z	p	z	p	z	p	z
With Nav. / No Nav.	.01*	-2.18	.20		.91		.10†	-1.47

We evaluated the navigation aid to be effective in comprehending the *layout* of web pages from simulated and RP participants. Statistical significance was found (p = .013), and the majority of the simulated participants reported that by following the navigation, they were able to see how the content is arranged with a minimum effort. Similarly, we received positive attitude towards the comprehension level of page *layout* from 5 RP participants. They described that the aid gave a hint on where they should look at the start of the page load. Even though they were simply given with an option to use the navigation, all of the participants from the two groups ended up activating the aid. Moreover, we could not actually observe faster search performance with the aid but they reported that less effort was made in finding relevant information. They mentioned that they had to otherwise wander for important information.

Even though the spatial layout of web pages was understood better with the aid, it did not empower the participants to grasp the overview. We revealed no significant difference with respect to *overview* comprehension between the two conditions. Similarly, the RP participants did not find the aid to be useful in grasping the *overview* of the content. Half of the RP members evaluated negatively with respect to a vague understanding of target content. The simulated participants also reported that they sometimes could not tell which part to attend within the target region and why they were guided to the region.

Such detection problem experienced by the two test groups revealed varying visual needs. For the RP participants, numbers represented in colored and/or bold fonts were easy to detect but other content such as images were regarded to be in low resolution. Need for higher contrast and zoom levels was mentioned for low vision. On the other hand, for the simulated participants, it was hard to decipher when multiple forms of information were presented within and around target regions. One simulated participant mentioned that "I could easily detect the search or add-to-cart button because it fits within the circle field. But it was hard to tell when the content size exceeds over the field."

The RP participants regarded the *search* experience to be improved with the aid. Four RP participants reported positive feedback because the aid sped up information processing of the whole screen. However, statistical significance for this accessibility aspect was not revealed from the simulated usability testing. Along with the feedback from the two RP participants who rated the ease of *search* on the negative range, it was easier for some participants to actively look for content of interest on the website. The aid was reported to be missing regions that they were expecting to be found through visual guidance.

There was a mild tendency regarding the comprehension of *spatial context* (p = .098). Moreover, one RP participant mentioned that using the aid helped her perceive the general structure of the page. We investigated that the level of *spatial contextual* understanding for the participants was influenced by prior experiences with the Web. At the interview session, we asked if the participants have visited the given sites. Within the two groups, the ones reported that they have not used those sites but are familiar with shopping with major e-commerce sites seemed to own spatial contextual awareness. Half of the RP participants were regular online shopping and Internet users, and they rated the level of *spatial context* on the positive range. The other half reported that they could not learn spatial relationships even when performing the tasks with the aid.

5.4 Discussion

Both positive and negative feedback on the evaluation criteria from the simulated study would be useful in our development and refinement of the navigation aid. Through the qualitative commonalities found between the two tests, we saw the opportunity to facilitate the investigation of further design requirements. Regarding the cognitive state, both test groups emphasized the less effort made in quickly finding important elements of a web page using our prototype. We analyzed that the aid offered a shortest path to gaze through the content for layout comprehension. Since the participants could not tell where to look at the start with the tunnel field of view, being able to efficiently move their gaze was crucial. With the knowledge of where important elements were located on the page, they did not have to feel stressed over if they were looking at the right section of the page.

With the simulated evaluation results, it would be ideal to run multiple feedback sessions throughout the design cycle. This empirical test sufficiently elicited similar design problems regarding selection and detection of target content. The problems led to negative feedback in content understanding among the two test groups. Participants added that the selection of target areas were different from where they usually focus on web pages. The order of guided regions was also described to be inconsistent with their natural gaze habits. Moreover, it was not easy to detect important content within the guided regions especially under the tunnel field of view. Content visibility necessary for each group yet emphasized varying needs in terms of detecting and perceiving the target content. For RP participants, even if they zoomed in the content where they had their point of gaze, the zoom level was still not enough to accommodate for their visual needs.

6. DESIGN IMPLICATIONS

Based on our empirical tests to investigate the role of simulation, we emphasize the additional component of simulation in bridging the transitions of design and evaluation components [25] in the design process. Our simulation-based approach can bring about the following qualities:

Designing. Simulation would support exploration of early design decisions to facilitate the conceptual design. Based on the analysis of our empirical study in usability testing compared between simulated tunnel vision and RP participants, feedback received by both groups at the early stages of designed interfaces were compatible with one another in terms of identifying functional aspects. We revealed that our simulation-based approach was useful to quickly probe the effect of half-baked ideas.

Evaluation. Subjective choice or preference of interface alternatives can be captured through simulated representative user trials. From usability testing, we were able to explore design alternatives and verify which one to carry forward to the next stage based on the obtained interface problems with relative navigation cues. Moreover, we did not discover any interface problems that were elicited solely due to evaluating the prototypes under a simulated tunnel field of view. Testing the prototypes with sighted participants under simulation will quickly reveal elementary UI and usability issues via controlled experiments.

Identification of Requirements. Developers can also pay attention to user behaviors and qualitative judgements from simulated tests. While statistical evaluation was also feasible due to controlled test conditions offered by the simulation-based approach, we saw the importance of enabling developers to consider human factors from simulated subjective perspectives. In this work, analyzing the simulated participants' performance on visual-search and online shopping tasks unraveled their cognitive states. For instance, from usability testing, simple and clear presentation of visual navigation cues (provided by the prototype AL in this study) alleviated their effort to perceive the instructions given under tunnel vision. Also, from user testing, our navigation aid was analyzed to limit cognitive load for layout understanding even though faster search performance was not observed.

We still saw that involving users with disabilities is still necessary in obtaining initial requirements and simulation should not be used in isolation. At the very beginning stage in the design cycle, user research in the form of interviews or observations in the field is still powerful in identifying initial requirements and design focus. However, the simulation-based approach can facilitate the transitions between design-decision making and prototyping efforts as the design proceeds to higher-fidelity prototyping. The simulation should be balanced with the test with the users with disabilities, especially when validating the user experience with high tech implementations.

7. CONCLUSION & FUTURE WORK

This paper presents a starting point to assess the role of the gaze-contingent tunnel vision simulator in a continual design-evaluation cycle. Our unique contribution is we clarified its implementation reliability in the actual development contexts via our empirical studies. Simulation-based approach has the the potential to encourage the designing of quick prototypes which can be cheaply tested to explore multiple ideas and evaluate their early design concepts to encourage further identification of accessible solutions. The developers can be also exposed to user feedback from simulated user trials, not only to examine problems in interfaces but also to gain necessary evaluation measures.

Our future work primarily involves investigating the effects of the simulation-based techniques from the viewpoints of the developers. It is important to observe how much developers feel the ease in their simulation-enabled design work to incorporate accessibility criteria. We also consider advancing our simulation system to support configuration for multiple visual conditions. However, there is little evidence in the advantages of simulating various vision impairments with different severity levels for defining design requirements to diverse needs. Our simulation techniques paid more attention to the HCI aspects and investigated how observing human behaviors via simulation could grasp both quantitative and qualitative feedback to enhance their design-decision making. We hope to support developers in determining the application of the simulation-based paradigm and encouraging accessible design.

8. REFERENCES

[1] P. Biswas and P. Robinson. Automatic evaluation of assistive interfaces. In *Proceedings of the 13th international conference on Intelligent user interfaces*, pages 247–256. ACM, 2008.

[2] P. Biswas, P. Robinson, and P. Langdon. Designing inclusive interfaces through user modeling and simulation. *International Journal of Human-Computer Interaction*, 28(1):1–33, 2012.

[3] K. Breiner, T. Wüchner, and M. Brunnlieb. The disability-simulator: simulating the influences of disabilities on the usability of graphical user interfaces. In *Proc. Int. Conf. Ergonomics and Health Aspects of Work with Computers*, pages 109–118. Springer, 2011.

[4] G. Buscher, E. Cutrell, and M. R. Morris. What do you see when you're surfing?: using eye tracking to predict salient regions of web pages. In *Proc. SIGCHI Conf. Human Factors in Computing Systems*, 2009.

[5] C. Cardoso and P. J. Clarkson. Simulation in user-centred design: helping designers to empathise with atypical users. *Journal of Engineering Design*, 23(1):1–22, 2012.

[6] S. Chang, L. Vaccarella, S. Olatunji, C. Cebulla, and J. Christoforidis. Diagnostic challenges in retinitis pigmentosa: genotypic multiplicity and phenotypic variability. *Current genomics*, 12(4):267–275, 2011.

[7] M. A. Duffy. Low vision and legal blindness terms and descriptions. http://www.visionaware.org/info/your-eye-condition/eye-health/low-vision/low-vision-terms-and-descriptions/1235, 2017. Accessed: 2017-1-16.

[8] D. R. Flatla and C. Gutwin. Individual models of color differentiation to improve interpretability of information visualization. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2563–2572. ACM, 2010.

[9] D. R. Flatla and C. Gutwin. So that's what you see: building understanding with personalized simulations

of colour vision deficiency. In *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility*, pages 167–174. ACM, 2012.

[10] P. Gadde and D. Bolchini. From screen reading to aural glancing: towards instant access to key page sections. In *Proc. Int. ACM SIGACCESS Conf. Computers & Accessibility*, pages 67–74, 2014.

[11] D. Giakoumis, N. Kaklanis, K. Votis, and D. Tzovaras. Enabling user interface developers to experience accessibility limitations through visual, hearing, physical and cognitive impairment simulation. *Universal Access in the Information Society*, 13(2):227–248, 2014.

[12] J. Goodman-Deane, S. Waller, A.-C. Collins, and P. J. Clarkson. Simulating vision loss: what levels of impairment are actually represented? 2013.

[13] J. Hailpern, M. Danilevsky, A. Harris, K. Karahalios, G. Dell, and J. Hengst. Aces: promoting empathy towards aphasia through language distortion emulation software. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 609–618. ACM, 2011.

[14] S. Keates and P. O. Looms. The role of simulation in designing for universal access. In *International Conference on Universal Access in Human-Computer Interaction*, pages 54–63. Springer, 2014.

[15] R. E. Kirk. *Latin square design.* Wiley Online Library, 2010.

[16] S. Kujala. User involvement: a review of the benefits and challenges. *Behaviour & information technology*, 22(1):1–16, 2003.

[17] R. E. Ladner. Design for user empowerment. *interactions*, 22(2):24–29, 2015.

[18] G. Luo and E. Peli. Patients with tunnel vision frequently saccade to outside their visual fields in visual search. *Journal of Vision*, 6(6):505–505, 2006.

[19] D. Maulsby, S. Greenberg, and R. Mander. Prototyping an intelligent agent through wizard of oz. In *Proc. SIGCHI Conf. Human Factors in Computing Systems*, pages 277–284, 1993.

[20] C. R. Miller and G. L. Allen. Spatial frames of reference used in identifying direction of movement: An unexpected turn. In *Proc. Int. Conf. Spatial Information Theory*, pages 206–216, 2001.

[21] A. F. Newell, P. Gregor, M. Morgan, G. Pullin, and C. Macaulay. User-sensitive inclusive design. *Universal Access in the Information Society*, 10(3):235–243, 2011.

[22] T. Oikonomou, K. Votis, D. Tzovaras, and P. Korn. Designing and developing accessible java swing applications. In *International Conference on Computers for Handicapped Persons*, pages 186–188. Springer, 2010.

[23] W. H. Organization. Visual impairment and blindness. http://www.who.int/mediacentre/factsheets/fs282/en/, 2017. Accessed: 2017-1-16.

[24] J. S. Perry and W. S. Geisler. Gaze-contingent real-time simulation of arbitrary visual fields. In *SPIE Proc. in Human Vision and Electronic Imaging*, pages 57–69, 2002.

[25] H. Plattner. An introduction to design thinking process guide. *The Institute of Design at Stanford: Stanford*, 2010.

[26] J. Preece, H. Sharp, and Y. Rogers. *Interaction Design-beyond human-computer interaction.* John Wiley & Sons, 2015.

[27] A. Sears and V. L. Hanson. Representing users in accessibility research. *ACM Transactions on Accessible Computing (TACCESS)*, 4(2):7, 2012.

[28] K. Shinohara, C. L. Bennett, and J. O. Wobbrock. How designing for people with and without disabilities shapes student design thinking. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*, pages 229–237. ACM, 2016.

[29] A. Squared. Zoomtext. http://www.aisquared.com, 2016. Accessed: 2016-9-21.

[30] S. F. A. Szpiro, S. Hashash, Y. Zhao, and S. Azenkot. How people with low vision access computing devices: Understanding challenges and opportunities. In *Proc. Int. ACM SIGACCESS Conf. Computers and Accessibility*, pages 171–180, 2016.

[31] H. Takagi, C. Asakawa, K. Fukuda, and J. Maeda. Accessibility designer: visualizing usability for the blind. In *ACM SIGACCESS Accessibility and Computing*, number 77-78, pages 177–184. ACM, 2004.

[32] H. Takagi, S. Saito, K. Fukuda, and C. Asakawa. Analysis of navigability of web applications for improving blind usability. *ACM Transactions on Computer-Human Interaction*, 14(3):13, 2007.

[33] Y. Takamoto and H. Tosaka. Web accessibility diagnosis tools. *FUJITSU Sci. Tech. J*, 41(1):115–122, 2005.

[34] M. F. Theofanos and J. G. Redish. Helping low-vision and other users with web sites that meet their needs: is one site for all feasible? *Technical communication*, 52(1):9–20, 2005.

[35] M. Vinnikov, R. S. Allison, and D. Swierad. Real-time simulation of visual defects with gaze-contingent display. In *Proc. Symposium on Eye Tracking Research & Applications*, pages 127–130. ACM, 2008.

[36] E. W. Wiecek, L. R. Pasquale, J. Fiser, S. Dakin, and P. J. Bex. Effects of peripheral visual field loss on eye movements during visual search. *Frontiers in psychology*, 3:472, 2012.

[37] J. O. Wobbrock, S. K. Kane, K. Z. Gajos, S. Harada, and J. Froehlich. Ability-based design: Concept, principles and examples. *ACM Transactions on Accessible Computing (TACCESS)*, 3(3):9, 2011.

[38] Y. Yesilada, C. Jay, R. Stevens, and S. Harper. Validating the use and role of visual elements of web pages in navigation with an eye-tracking study. In *Proc. Int. Conf. World Wide Web*, 2008.

[39] B. H. Zeavin and G. Wald. Rod and cone vision in retinitis pigmentosa. *American journal of ophthalmology*, 42(4):253–269, 1956.

[40] E. Zitkus, P. Langdon, and J. Clarkson. Accessibility evaluation: Assistive tools for design activity in product development. In *SIM conference proceedings*, volume 1, pages 659–670, 2011.