Analysis of Free Browser-based Accessibility Tools: WCAG 2.1 Evaluation of Mississippi Gulf Coast Public Library Websites

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INTRODUCTION

The popularity of digital information has highlighted the importance of web resources becoming accessible and usable for diverse populations close to home and afar. For public libraries, meeting community needs has gone beyond physical resources and assistance, extended to continuous resources of their creation, such as library websites. Web accessibility has been mandated in many private, public, and government business sectors. The United States government has required accessibility standards to be implemented for those who need assistive technologies to navigate web pages for federal and academic institutions (W3C, 2021d).

The World Wide Web Consortium (W3C) explained web accessibility as the awareness of disabilities within the design and development of all areas of the Web to remove information barriers (World Wide Web Consortium [W3C], 2021b). As a worldwide leader in both areas, the World Wide Web Consortium began the Web Accessibility Initiative (WAI)—a joint effort with disability organizations, governments, and other entities to understand information barriers and develop practical standards for inclusive information flow on the Web.

Modern web design and content did not automatically comply with the current accessibility standards despite improvements and regulations to content management systems. Template web designs were often considered a visual art form, ignoring that the visible item cannot always be seen and may act more as a censor by limiting the information path. As web accessibility compliance was a specialty of its own, browser-based web tools have appeared over time to automate accessibility analyses and facilitate simplified human-led evaluations of site content.

Web Content Accessibility Guidelines, also known as WCAG, version 2.1 (WCAG2.1) was introduced in its first iteration in 2017 and builds on without replacing previous guidelines. "For web accessibility—making the World Wide Web equally accessible for all users, regardless of physical or cognitive ability—WCAG 2.0 by the World Wide Web Consortium (W3C) is the gold standard. Its AA level of compliance is the main reference point for accessibility standards the world over, including the United Nations, European Union, and the United States, among others" (Stemler, 2018). WCAG2.1 has 17 key differences. This study measured library website compliance on WCAG2.1.

Problem Statement

The purpose of this webometrics study was to compare free browser-based accessibility tools and determine the WCAG2.1 compliance levels of Mississippi Gulf Coast public library websites based on homepage analysis through free browser-based accessibility tools—ARC Toolkit, Lighthouse, Accessibility Insights for the Web, and Axe Accessibility.

Research Questions

R1: What WCAG2.1 compliance areas did free browser-based accessibility tools test?

R2: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per ARC Toolkit?

R3: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per Lighthouse?

R4: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per Accessibility Insights for the Web?

R5: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per Axe Accessibility?

R6: Did the free browser-based accessibility tools provide a consistent evaluation of WCAG2.1 standards?

Definitions

assistive technology: "hardware and/or software that acts as a user agent, or along with a mainstream user agent, to provide functionality to meet the

requirements of users with disabilities that go beyond those offered by mainstream user agents" (W3C, 2018).

Cascading Style Sheets (CSS): "language for describing the presentation of Web pages, including colors, layout, and fonts" (W3C, 2018).

captions: "synchronized visual and/or text alternative for both speech and non-speech audio information needed to understand the media content" (W3C, 2018).

conformance: "satisfying all the requirements of a given standard, guideline or specification" (W3C, 2018).

content (Web content): "information and sensory experience to be communicated to the user by means of a user agent, including code or markup that defines the content's structure, presentation, and interactions" (W3C, 2018).

contrast ratio: "(L1 + 0.05) / (L2 + 0.05), where L1 is the relative luminance of the lighter of the colors, and L2 is the relative luminance of the darker of the colors" (W3C, 2018).

Extensible Markup Language (XML): "simple text-based format for representing structured information" (W3C, 2015).

Hypertext Markup Language (HTML): "language for describing the structure of Web pages" (W3C, 2016).

keyboard shortcut: "alternative means of triggering an action by the pressing of one or more keys" (W3C, 2018).

label: "text or other component with a text alternative that is presented to a user to identify a component within Web content" (W3C, 2018).

Scalable Vector Graphics (SVG): "markup language for describing two-dimensional graphics applications and images, and a set of related graphics script interfaces" (W3C, 2010).

structure: "the way the parts of a Web page are organized in relation to each other and the way a collection of Web pages is organized" (W3C, 2018).

style property: "property whose value determines the presentation (e.g. font, color, size, location, padding, volume, synthesized speech prosody) of content elements as they are rendered by user agents" (W3C, 2018).

technology (Web content): "mechanism for encoding instructions to be rendered, played or executed by user agents" (W3C, 2018).

user agent: "any software that retrieves and presents Web content for users" (W3C, 2018).

user interface component: "a part of the content that is perceived by users as a single control for a distinct function" (W3C, 2018).

Web page: "a non-embedded resource obtained from a single URI using HTTP plus any other resources that are used in the rendering or intended to be rendered together with it by a user agent" (W3C, 2018).

Delimitations

The Mississippi libraries evaluated were limited to the "Coastal Region" designated by the Mississippi Library Commission's public library directory (2020). Web accessibility assessments were limited to the main library system home pages. Accessibility evaluations were limited to the free versions of browser-based accessibility tools and developer directives. Manual evaluations were limited to errors flagged in accessibility tool reports.

Assumptions

Webpages were assumed to be current and properly managed. Free browser-based tools were assumed to contain accurate, current, and factual information and accurate and current coding for site assessment and reporting according to current WCAG 2.1 accessibility standards.

Importance of the Study

The information provided in this study may assist web accessibility evaluation in public libraries and compliance checks in other institution types to meet web accessibility milestones. The study contributed to

the overall literature on web accessibility and assessment tools.

LITERATURE REVIEW
Web Accessibility Guidelines
The American Library Association (ALA) defined accessibility as "making your data understandable by all users, considering users with special needs and abilities" (2021b). Traditionally, libraries strived to adhere to U.S. regulations and international standards for accessibility, including the Americans with Disability Act, Communications Act, and Rehabilitation Act, so web accessibility was a logical next step for the community resource (U.S. Access Board, 2017; U.S. Department of Justice, 2017). Barbara Tearle gave a practical example of compliance in a 2004 publication targeting libraries' compliance to the Special Educational Needs and Disability Act 2001. Tearle discussed the accessibility adjustments made in a law library to promote independence in research for people with disabilities. Specific changes made to the library website included text layout, text font, and color contrast to improve the site's compatibility with assistive technologies and site usage for people with visual impairments (Tearle, 2004).

Nearing the turn of the century, the World Wide Web Consortium generated and published the inaugural list of best practices to develop accessible web content, called the Web Content Accessibility Guidelines. The Web Content Accessibility Guidelines (WCAG) were meant to demystify accessibility compliance, describe best practices for user-centric web design, and guide accessibility and usability assessments in current sites (W3C, 2021b). According to W3C, the fundamental benchmarks driving the Web Content Accessibility Guidelines are the Four Principles of Accessibility (W3C, 2021e). WCAG presented best practices to oversee and standardize each of the four content and information areas: perceivable, operable, understandable, and robust (W3C, 2021e). Within these four areas, the World Wide Web Consortium established the requirements that: content and information must be perceived by at least one user sense, interfaces must be user-friendly and action appropriate, information and interfaces must be simple with limited usage instruction required, and content must meet and continue to fulfill accessibility standards for use with assistive technologies (2021e).

Examples include captions, labels, content and text structure, contrast ratio, keyboard shortcut, site navigation, style property, unique element identifier, and complete markup language (W3C, 2021a).

Three levels were used to rank testable criteria: A, AA, and AAA (W3C, 2021c). Level A was minimal compliance with web accessibility guidelines. Level AA was essential compliance with WCAG for user accessibility. Level AAA was high-level compliance. In 2018, W3C stated Level AAA should not "be required as a general policy for entire sites because it is not possible to satisfy all Level AAA Success Criteria for some content." The AA level was the success rating recommended to ensure the optimum user experience (W3C, 2018). Examples of organizations that aimed for the AA rating included the American Library Association and the University of Southern Mississippi (ALA, 2021a; University of Southern Mississippi, 2019).

Web Accessibility Evaluation and Research
One study discussed the automated evaluation of homepages to determine web accessibility issues per the Web Content Accessibility Guidelines (Lazar, Beere, Greenidge, and Nagappa, 2003). The authors determined website compliance and automated tool were measurable using site homepages. In this study, automated accessibility checks were not exclusive, requiring manual site checks for complete evaluation (2003). Similarly, in 2020, another study assessed web accessibility evaluation tools and methodologies. Alsaeedi (2020) discussed the variability of accessibility tool reporting in (for-purchase) accessibility software and studied the homepage exclusively because they were "indicators for other webpages and the starting points for visitors" (2020).

The comparative analysis of different approaches to compliance testing indicated the benefits and downfalls of potential evaluation methods for web accessibility. The group noted that web assessment methods were rarely classified, researched, or compared (Zahran, Al-Nuaim, Rutter, and Benyon, 2010). The lack of information was attributed potentially to the misuse of evaluation terminology (Web vs. Website), which misrepresented the intent of the studies analyzed (Zahran et al., 2010). The group argued for a two-method evaluation that included automatic and human-led testing using an older

research method in tandem with newer evolving techniques for a checks-and-balances approach (Zahran et al., 2010).

Cynthia Ng addressed the benefits of universal design for web accessibility in her 2017 best practices guide. Ng noted the limitations of automated accessibility tools due to false positive and false negative reporting and recommended manually evaluating automated compliance reports. Ng discussed the significance of understanding online content development and web accessibility best practices before any report interpretation or error resolution. For example, Ng remarked on the lack of user experience captured in automated tools and recommended human evaluation as regular accessibility checks (2017).

Spina discussed the continued lack of accessibility compliance in library websites per WCAG 2.1 guidelines due to a lack of funds, personnel, and guidance. The author discussed the importance of prioritizing accessibility compliance in budgets and workflows and adding layers of compliance testing and training, such as capturing the perspective of assistive technology users, to create a thorough assessment of compliance beyond the limitations of web accessibility tools (Spina, 2019). Specifically, Spina stated, "automated accessibility testing using free or subscription-based tools is a central element of accessibility work" to overcome resource deficiencies (2019).

Researchers Panda and Chakravarty evaluated IIT libraries' web accessibility through a browser-based accessibility tool compatible with multiple browsers (2020). The study concluded that the accessibility tool used followed the best practices set in the Web Content Accessibility Guidelines and was an acceptable measurement of compliance for website inclusivity (2020). Another study reported on university websites using automated tools and barrier walkthrough of the WCAG framework defined within the accessibility tools in 2019. The authors discussed the importance of applying human-led assessments of web accessibility along with available automated tools to design inclusive websites for multiple disabilities (Acosta-Vargas et al., 2019).

Similar to the previous studies, this study analyzed web accessibility through website sampling based on

Web Content Accessibility Guidelines in automated and manual forms. The evaluation included automated assessments of web accessibility using browser-based tools based on the best practices outlined in the Web Content Accessibility Guidelines. Additionally, manual tests evaluated the suggestions, errors, and warnings reported by the free browser-based accessibility tools. The combination of automated and manual compliance assessments offset the downfalls of using one evaluation method.

METHODOLOGY
Five Mississippi Gulf Coast public library website homepages were assessed for web accessibility compliance on three levels: A, AA, and AAA. The library sites were evaluated as they appeared during the assessment in September 2021. The library home pages reviewed were the Hancock County Library System site (https://hancocklibraries.info), the Harrison County Library System site (https://harrison.lib.ms.us/), the Jackson-George Regional Library site (http://www.jgrls.org/), the Long Beach Public Library site (https://longbeach.lib.ms.us/), and the Pearl River County Library site (https://pearlriver.lib.ms.us/). In this webometrics study, the libraries were assigned a unique identifier (L1, L2, L3, L4, and L5) for anonymity. The following four free browser-based tools were utilized to evaluate the homepages of the Hancock, Harrison, Jackson-George, Pearl River, and Long Beach public libraries: Axe Accessibility, Accessibility Insights for the Web, ARC Toolkit, and Lighthouse.

Information Sources and Procedures
The browser-based tools were used in free developer modes in Google Chrome, Mozilla Firefox, and Microsoft Edge per the evaluation tool standards. The level of compliance was based on the reports delivered by the automated tools and guided, manual evaluations. The home sites were accessed in online mode through the three browsers Google Chrome, Mozilla Firefox, and Microsoft Edge.

Accessibility tools were included in each applicable browser type as an extension. Each tool extension was enabled (via the browser extension bar or developer tool) within the browser tab where the public library home page was open. For optimum results, the

evaluation followed on-screen prompts and guidelines provided by the developers of the accessibility tool. The accessibility area evaluated in each report was reviewed to determine the WCAG 2.1 compliance sections tested by the free browser-based accessibility tools.

All data were collected and stored in HTML and XML documents. Success criteria compliance areas were referred to by WCAG category: perceivable (discernable by human sense), operable (usable by human or machine), understandable (intelligible), and robust (variable and sustainable) (2021e). Failure to meet WCAG success criteria were noted as errors. Data collection included the unique library identifiers, errors reported per browser by each accessibility tool, false positive or negative results from manual evaluation of reported errors, and the category, level, and rule violation of each error. The results of the study were formatted as graphs and tables in Excel.

The web accessibility level for each public library resulted from a one-time compliance check; therefore, the level cannot be applied continuously without additional testing.

Public library homepages were reviewed once in September 2021, and analyses were based on the one-time data collection for each public library page with supposedly accurate and working web accessibility tools. The results of this study cannot be generalized to all public libraries or libraries within Mississippi.

RESULTS
R1: What WCAG2.1 compliance areas did free browser-based accessibility tools test?
Approximately twenty-two percent of the seventy-eight WCAG success criteria were tested via automatic tools (see Table 1). All tools audited at least one rule in the perceivable, operable, understandable, and robust WCAG categories (see Figure 1 for percentages and Table 1 for rule list). The perceivable category accounted for eight of the seventeen (47%) success criteria. Five of the seventeen criteria (29%) were in the operable category. Understandable and robust categories held two tested success criteria (12%) each.
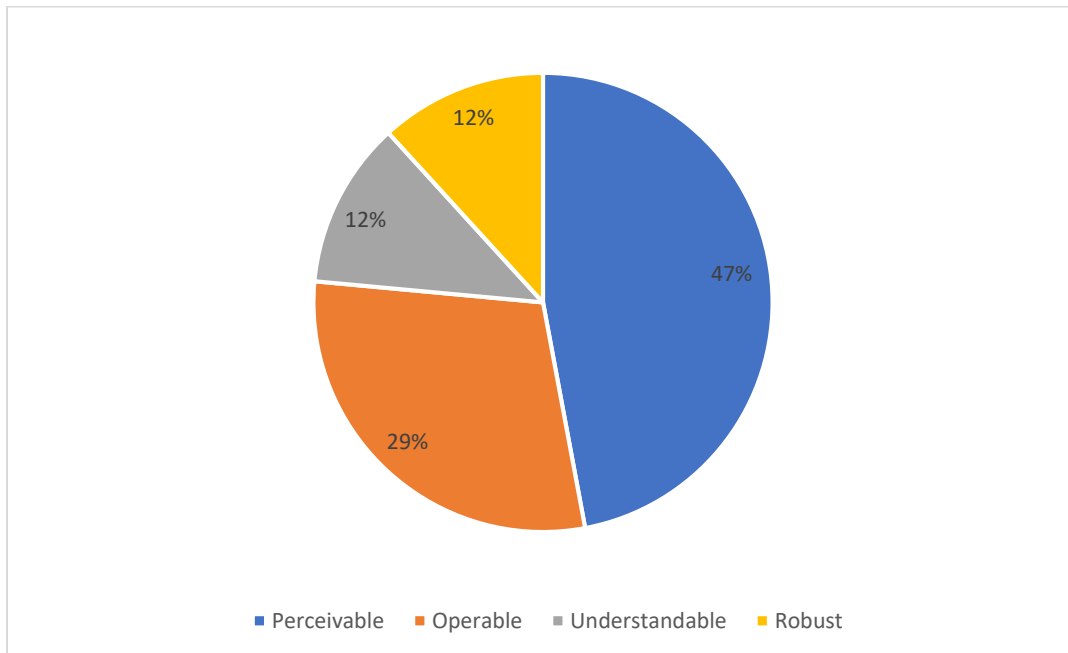

Figure 1. *WCAG Category Percentage Reported by Tools*

WCAG Rule	Level	ARC	LH	AI	AXE
Perceivable					
1.1.1 non-text content	A	X	X	X	X
1.2.2 captions (prerecorded)	A	X	X	X	X
1.2.3 audio description or media alternative (prerecorded)	A	X	-	-	-
1.3.1 info and relationships	A	X	X	X	X
WCAG Rule (continued)	**Level**	**ARC**	**LH**	**AI**	**AXE**
Perceivable					
1.3.5 identify input purpose	AA	X	-	-	-
1.4.3 contrast (minimum)	AA	X	X	X	X
1.4.4 resize text	AA	X	-	-	-
1.4.12 text spacing	AA	-	-	X	-
Operable					
2.1.1 keyboard	A	X	-	-	-
2.4.1 bypass blocks	A	X	X	X	X
2.4.2 page titled	A	X	X	X	X
2.4.4 link purpose (in context)	A	X	X	X	X
2.4.6 headings and labels	AA	X	-	-	-
Understandable					
3.1.1 language of page	A	X	X	X	X
3.3.2 labels or instructions	A	X	-	-	-
Robust					
4.1.1 parsing	A	X	X	X	X
4.1.2 name, role, value	A	X	X	X	X

Table 1. *Tested Criteria per Tool based on All Reports*

ARC Toolkit tested sixteen success criteria with seventy-five percent on Level A and the remaining on Level AA (see ARC in Table 1). Lighthouse audited ten rules with ninety percent on Level A and the remaining on Level AA (see LH in Table 1). Accessibility Insights for the Web tested eleven with almost eighty-two percent on Level A and the remaining on Level AA (see AI in Table 1). Nine were in Level A. Two were in Level AA. Axe Accessibility tested ten rules, with ninety percent on Level A and the remaining on Level AA (see AXE in Table 1). Level AAA was not tested on any level by any tool.

R2: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per ARC Toolkit?

ARC Toolkit evaluated accessibility in Google Chrome (see Figure 2 and Table 2). The audit reported at least one error in each of the four categories. The tool highlighted thirteen issues (see Table 2). Twelve of the thirteen issues violated WCAG 2.1 conformance on Level A, and the thirteenth violated conformance on Level AA. Google Chrome reported a total of 129 errors. Twenty-four errors simultaneously violated two WCAG areas.
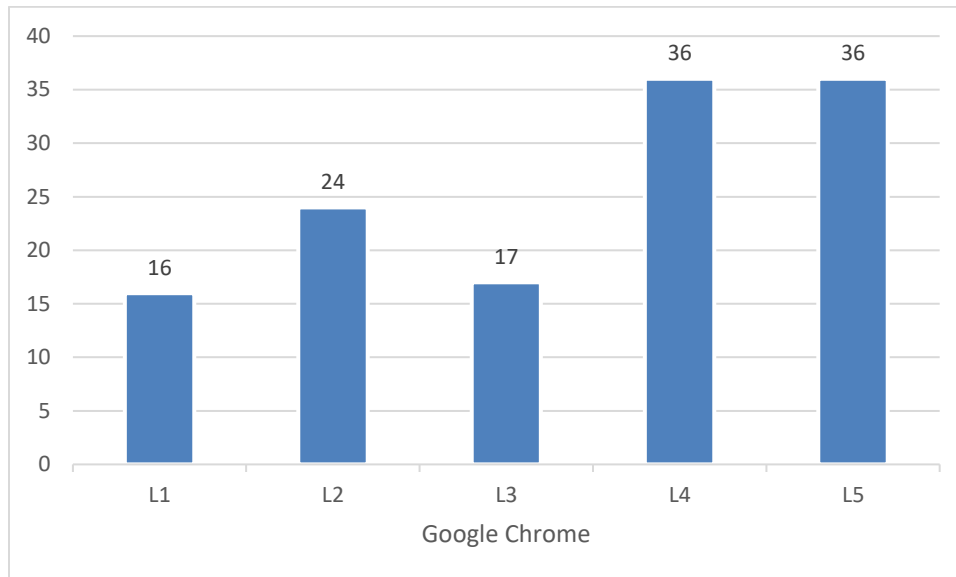
Figure 2. *Library Errors per ARC Toolkit*

| Issue | Google Chrome | | | | |
	L1	L2	L3	L4	L5
image text	-	-	11	-	3
SVG text	-	-	2	-	-
form label	2	3	-	1	1
color contrast	9	14	-	22	30
block bypass	-	1	-	1	1
frame title	1	1	-	-	-
document title	-	-	1	1	-
link name	1	5	2	7	-
HTML language	-	-	-	-	1
duplicate id	1	-	1	-	-
allowed aria	1	-	-	-	-
aria role	1	-	-	-	-
required aria	-	-	-	4	-

Table 2. *ARC Toolkit Errors in Google Chrome*

All errors were rated serious or critical to user impact (Deque University, 2021). The critical user impact rate accounted for more than twenty-two percent of the total errors. All errors were on Level A or AA. Approximately forty-two percent of the errors were on Level A, with fifty-two percent rated critical to user impact. On Level AA, all errors were rated serious to user impact (Deque University, 2021). The disabilities affected were blind, cognitive, colorblindness, deaf, deafblind, low vision, and mobility (Deque University, 2021). Manual accessibility checks were performed on reported errors. Automatic accessibility tools correctly identified success criteria failures. According to ARC Toolkit data, the libraries did not successfully meet all required criteria for WCAG 2.1 compliance on any level in Google Chrome. Additionally, five of the thirteen issues (block bypass, form label, frame title, image text, and link name) violated Section 508 of the Rehabilitation Act (29 U.S.C. § 794d) (Deque University, 2021; U.S. Access Board, 2001; U.S. Access Board, 2021).

R3: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per Lighthouse?

Lighthouse evaluated accessibility in Google Chrome and Microsoft Edge (see Figure 3 and Table 3). The audit reported at least one error in each of the four categories. The tool highlighted nine main issues across the four WCAG areas (see Table 3). Eight of the nine issues violated WCAG 2.1 conformance on Level A, and the ninth violated conformance on Level AA. Google Chrome reported a total of 105 errors (see Figure 3). Sixteen of those errors violated two WCAG areas and rules. The critical user impact rate accounted for less than twelve percent of the total errors. Approximately twenty-nine percent of the errors were on Level A, with thirty-eight percent rated critical to user impact. Microsoft Edge reported a total of 66 errors (see Figure 3). Sixteen of those errors violated two WCAG areas and rules. The critical user impact rate accounted for more than ten percent of the total errors. Approximately thirty-nine percent of the errors were on Level A, with twenty-six percent rated critical to user impact.

In both browsers, all errors were rated serious or critical to user impact (Deque University, 2021). All errors were on Level A or AA. On Level AA, all errors were rated serious to user impact. The disabilities affected were blind, cognitive, color-blindness, deaf, deafblind, low vision, and mobility (Deque University, 2021).
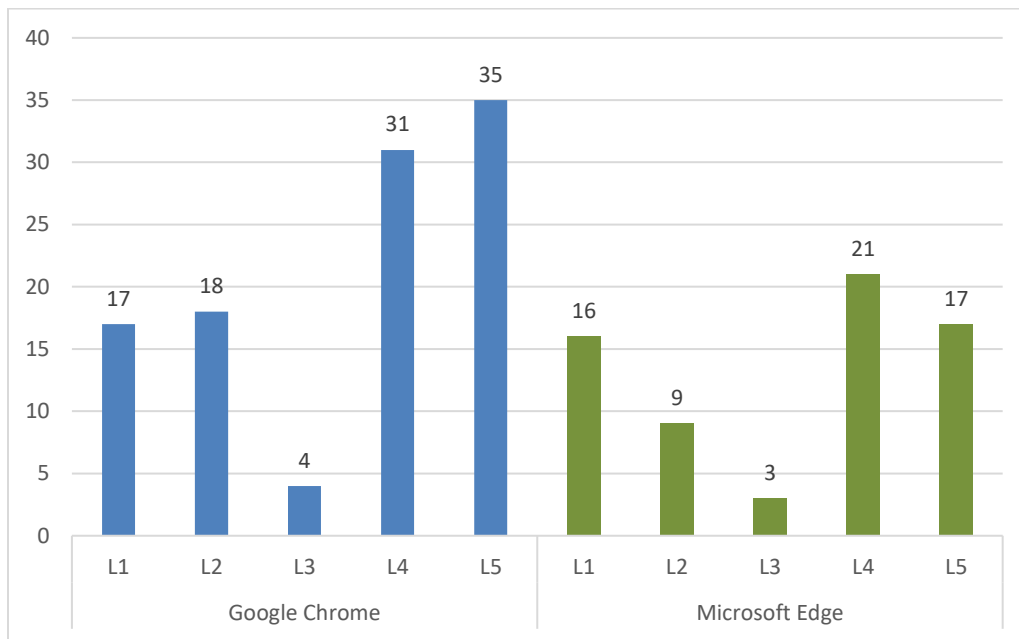

Figure 3. *Library Errors per Lighthouse*

Issue	Google Chrome					Microsoft Edge				
	L1	L2	L3	L4	L5	L1	L2	L3	L4	L5
image text	-	1	-	-	2	-	1	-	-	2
form label	1	1	-	-	1	1	1	-	-	1
color contrast	13	9	-	22	30	13	1	-	13	13
frame title	1	-	-	-	-	1	-	-	-	-
document title	-	-	1	1	-	-	-	1	1	-
link name	1	5	2	7	-	1	5	2	7	-
HTML language	-	-	-	-	1	-	-	-	-	1
duplicate id	-	1	-	-	-	-	1	-	-	-
allowed aria	1	1	1	1	1	-	-	-	-	-

Table 3. *Lighthouse Errors in Google Chrome and Microsoft Edge*

Manual accessibility checks were performed on reported errors. Automatic accessibility tools correctly identified success criteria failures with one exception: hierarchical headings. According to Lighthouse data, the libraries did not successfully meet all required criteria for WCAG 2.1 compliance on any level in Google Chrome or Microsoft Edge. In both browsers, four of the issues (form label, frame title, image text, and link name) violated Section 508 of the Rehabilitation Act (29 U.S.C. § 794d) (Deque University, 2021; U.S. Access Board, 2001; U.S. Access Board, 2021).

R4: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per Accessibility Insights for the Web?
Accessibility Insights for the Web evaluated accessibility in Google Chrome and Microsoft Edge (see Figure 4 and Table 4). The audit reported at least one error in each of the four categories. The tool highlighted nine main issues (see Table 4). Eight of the nine issues violated WCAG 2.1 Level A, and the ninth failed Level AA conformance. Google Chrome reported a total of 107 errors. Sixteen of those errors violated two WCAG areas and rules. The critical user impact rate accounted for more than thirteen percent of the total errors. Approximately thirty percent of the errors were on Level A, with forty-two percent rated critical to user impact. Microsoft Edge reported a total of 100 errors. Sixteen of those errors violated two WCAG areas and rules. The critical user impact rate accounted for seven percent of the total errors. Approximately twenty-six percent of the errors were on Level A, with twenty-seven percent rated critical to user impact.
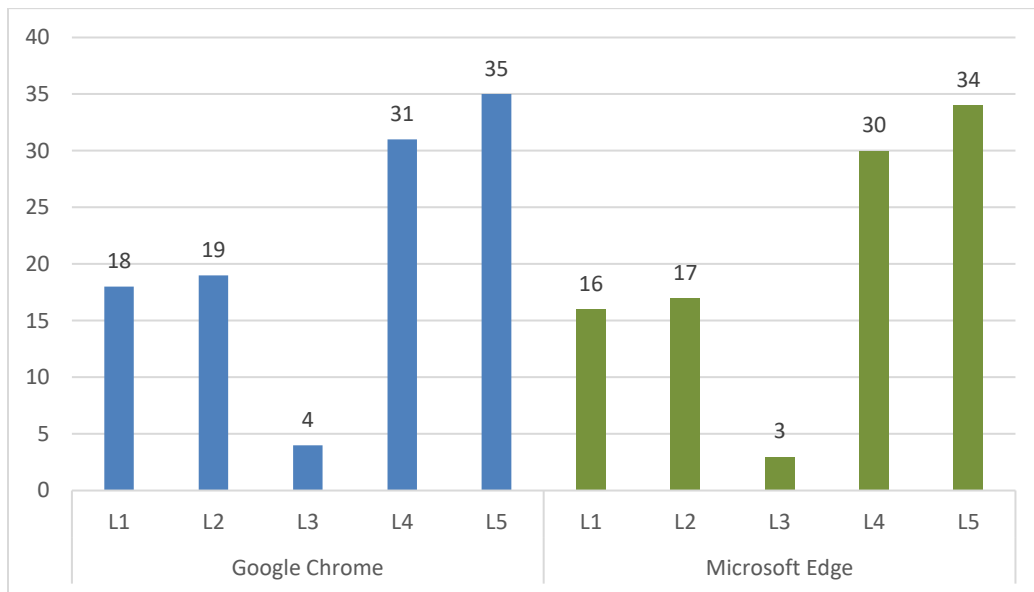

Figure 4. *Library Errors per Accessibility Insights for the Web*

Issue	Google Chrome					Microsoft Edge				
	L1	L2	L3	L4	L5	L1	L2	L3	L4	L5
image text	-	1	-	-	2	-	1	-	-	2
form label	1	1	-	-	1	1	1	-	-	1
color contrast	13	9	-	22	30	13	9	-	22	30
frame title	1	-	-	-	-	1	-	-	-	-
document title	-	-	1	1	-	-	-	1	1	-
link name	1	5	2	7	-	1	5	2	7	-
HTML language	-	-	-	-	1	-	-	-	-	1
duplicate id	-	1	-	-	-	-	1	-	-	-
allowed aria	2	2	1	1	1	-	-	-	-	-

Table 4. *Accessibility Insights for the Web Errors in Google Chrome and Microsoft Edge*

In both browsers, all errors were rated serious or critical to user impact (Deque University, 2021). All errors were on Level A or AA. On Level AA, all errors were rated serious to user impact. The disabilities affected were blind, cognitive, colorblindness, deaf, deafblind, low vision, and mobility (Deque University, 2021). Manual accessibility checks were performed on reported errors. Automatic accessibility tools correctly identified success criteria failures. According to Accessibility Insights for the Web data, the libraries did not successfully meet all required criteria for WCAG 2.1 compliance on any level in Google Chrome or Microsoft Edge. In both browsers, four of the issues (form label, frame title, image text, and link name) violated Section 508 of the Rehabilitation Act (29 U.S.C. § 794d) (Deque University, 2021; U.S. Access Board, 2001; U.S. Access Board, 2021).

R5: What WCAG2.1 compliance level(s) did public library websites meet in the Mississippi Gulf Coast region per Axe Accessibility?
Axe Accessibility evaluated accessibility in Google Chrome, Microsoft Edge, and Mozilla Firefox (see

Figure 5 and Table 5). The audit reported at least one error in each of the four categories. The tool highlighted eleven main issues (see Table 5). Ten of the eleven issues violated WCAG 2.1 conformance on Level A, and the eleventh violated conformance on Level AA. Google Chrome reported a total of 136 errors (see Figure 5). Sixteen of those errors violated two WCAG areas and rules. The critical user impact rate accounted for more than ten percent of the total errors. Approximately twenty-five percent of the errors were on Level A, with forty-one percent rated critical to user impact. Microsoft Edge reported a total of 121 errors (see Figure 5). Sixteen of those errors violated two WCAG areas and rules. The critical user impact rate accounted for less than six percent of the total errors. Approximately twenty-two percent of the errors were on Level A, with twenty-six percent rated critical to user impact. Mozilla Firefox reported a total of 135 errors (see Figure 5). Sixteen of those errors violated two WCAG areas and rules. Critical user impact rate accounted for less than six percent of the total errors. About twenty percent were Level A errors, with twenty-six percent rated critical to user impact.
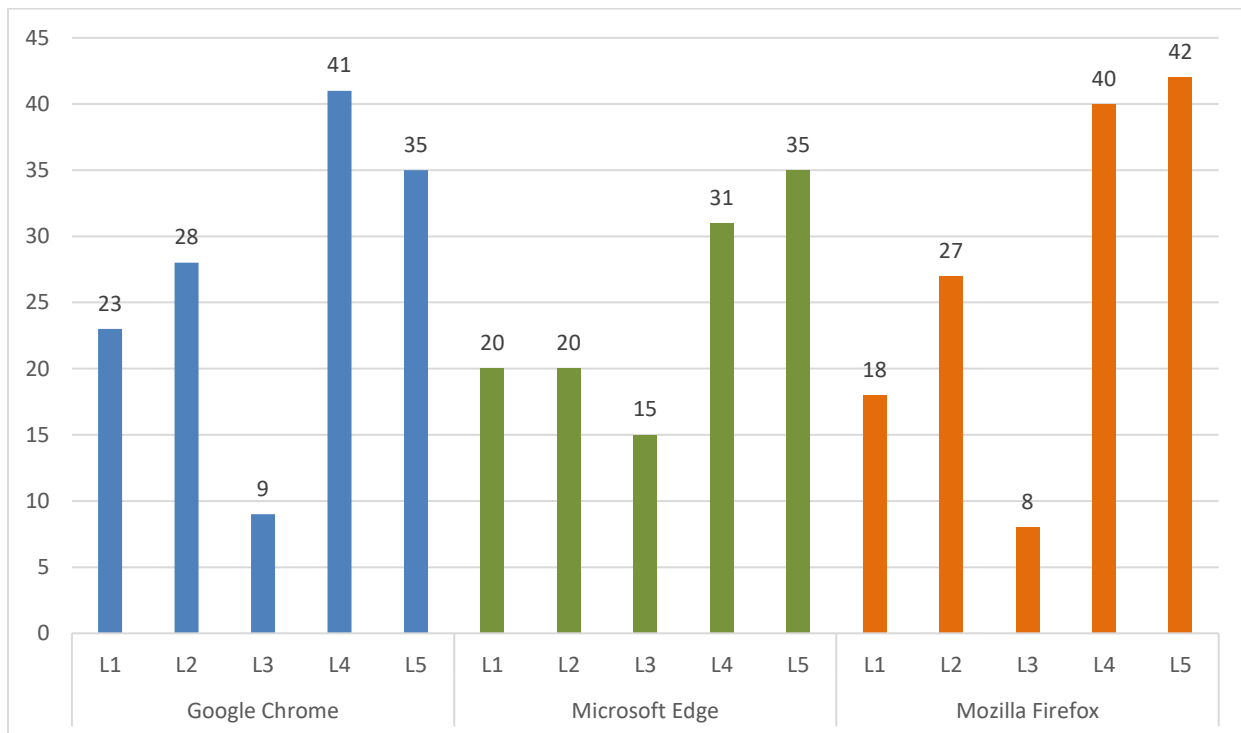

Figure 5. *Library Errors per Axe Accessibility*

Issue	Google Chrome					Microsoft Edge					Mozilla Firefox				
	L1	L2	L3	L4	L5	L1	L2	L3	L4	L5	L1	L2	L3	L4	L5
image text	-	1	-	-	2	-	1	-	-	2	-	1	-	-	2
video caption	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
form label	1	1	-	-	1	1	1	-	-	1	1	1	-	-	1
th data cells	-	1	-	-	-	-	1	-	-	-	-	1	-	-	-
color contrast	16	18	5	32	31	17	11	12	23	31	15	18	5	32	38
frame title	1	-	-	-	-	1	-	-	-	-	1	-	-	-	-
document title	-	-	1	1	-	-	-	1	1	-	-	-	1	1	-
link name	1	5	2	7	-	1	5	2	7	-	1	5	2	7	-
HTML language	-	-	-	-	1	-	-	-	-	1	-	-	-	-	1
duplicate id	-	1	-	-	-	-	1	-	-	-	-	1	-	-	-
allowed aria	3	1	1	1	-	-	-	-	-	-	-	-	-	-	-

Table 5. *Axe Accessibility Errors in All Browsers*

In both browsers, all errors were rated serious or critical to user impact (Deque University, 2021). All errors were on Level A or AA. On Level AA, all errors were rated serious to user impact. The disabilities affected were blind, cognitive, colorblindness, deaf, deafblind, low vision, and mobility (Deque University, 2021). Manual accessibility checks were performed on reported errors. Automatic accessibility tools correctly identified success criteria failures. According to Accessibility Insights for the Web data, the libraries did not successfully meet all required criteria for WCAG 2.1 compliance on any level in Google Chrome, Microsoft Edge, Mozilla Firefox. In all browsers, five of the issues (form label, frame title, image text, link name, and th data cells) violated Section 508 of the Rehabilitation Act (29 U.S.C. § 794d) (Deque University, 2021; U.S. Access Board, 2001; U.S. Access Board, 2021).

R6: Did the free browser-based accessibility tools provide a consistent evaluation of WCAG2.1 standards?

All tools reported at least one error in all four categories. Browser availability altered per tool (see Figure 6 and Table 6). ARC Toolkit was compatible with Google Chrome only, therefore, not compared across browsers (see ARC in Figure 6 and Table 6). Lighthouse reports in Google Chrome and Microsoft Edge were identical with two exceptions: the number of color contrast errors varied by browser and Microsoft Edge reported no errors for allowed ARIA attributes (see LH in Figure 6 and Table 6). Accessibility Insights for the Web reports in Google Chrome and Microsoft Edge were identical with one exception: Microsoft Edge reported no errors for allowed ARIA attributes (see AI in Figure 6 and Table 6). Axe Accessibility reports in Google Chrome, Microsoft Edge, and Mozilla Firefox were identical with two exceptions: the number of color contrast errors varied in all browsers, and Microsoft Edge and Mozilla Firefox reported no errors for allowed ARIA attributes (see AXE in Figure 6 and Table 6). Mozilla Firefox was only compatible with Axe Accessibility; therefore, no tool comparison was available across the browser.

ARC Toolkit reported the highest number of image text issues (14) (see Table 6). The tool reported eleven more errors than the three noted by Lighthouse, Accessibility Insights for the Web, and Axe Accessibility. Lighthouse and Accessibility Insights for the Web matched eighty-nine percent of errors recorded in Google Chrome and eighty-eight percent in Microsoft Edge. Axe Accessibility reported the highest number of errors (136), and ARC Toolkit reported the second highest (129) in Google Chrome (see ARC and AXE in Figure 6 and Table 6).
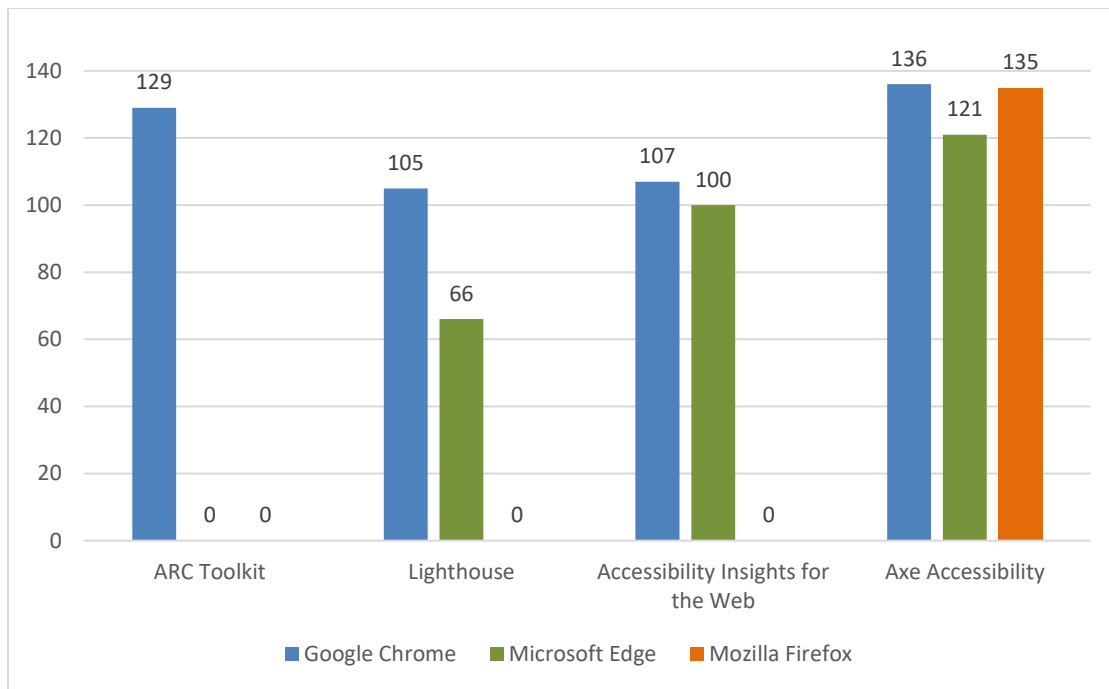
Figure 6. *Tool Errors per Browser*

Issue	Google Chrome				Microsoft Edge				Mozilla Firefox			
	ARC	LH	AI	AXE	ARC	LH	AI	AXE	ARC	LH	AI	AXE
image text	14	3	3	3	-	3	3	3	-	-	-	3
SVG text	2	-	-	-	-	-	-	-	-	-	-	-
video-caption	-	-	-	1	-	-	-	-	-	-	-	-
form label	7	3	3	3	-	3	3	3	-	-	-	3
th-has-data-cells	-	-	-	1	-	-	-	1	-	-	-	1
color contrast	75	74	74	102	-	40	74	94	-	-	-	108
block bypass	3	-	-	-	-	-	-	-	-	-	-	-
frame title	2	1	1	1	-	1	1	1	-	-	-	1
document title	2	2	2	2	-	2	2	2	-	-	-	2
link name	15	15	15	15	-	15	15	15	-	-	-	15
HTML language	1	1	1	1	-	1	1	1	-	-	-	1
duplicate id	2	1	1	1	-	1	1	1	-	-	-	1
allowed aria	1	5	7	6	-	0	0	-	-	-	-	-
aria role	1	-	-	-	-	-	-	-	-	-	-	-
required aria	4	-	-	-	-	-	-	-	-	-	-	-

Table 6. *Tool Errors in All Browsers*

Axe Accessibility reported the highest number of errors (121), and Accessibility Insights for the Web reported the second highest (100) in Microsoft Edge (see AI and AXE in Figure 6 and Table 6). Axe Accessibility was the highest (135) and only audit available for Mozilla Firefox (see AXE in Figure 6 and Table 6). Overall, Axe Accessibility reported the largest number of issues in each of the three browsers when compared to other tools (see AXE in Figure 6 and Table 6). The higher amount of errors was directly contributed to the color contrast issue, which failed WCAG 1.4.3 contrast (minimum) success criteria. The average difference was twenty-eight in Google Chrome and thirty-seven in Microsoft Edge.

DISCUSSION
This study tested the accessibility of public library websites along the Mississippi Gulf Coast in

September 2021. Assessments were based on WCAG success criteria on three levels: A, AA, and AAA. The home pages of Harrison, Hancock, Long Beach, Pearl River, and Jackson-George libraries were assessed via four free versions of browser-based accessibility tools (Axe Accessibility, Accessibility Insights for the Web, ARC Toolkit, and Lighthouse) in the browsers Google Chrome, Microsoft Edge, and Mozilla Firefox. Errors were documented and checked for false positive and false negative reporting. The accessibility tools did not assess Level AAA, so all errors were on Level A or AA. Zero of five libraries completed the success criteria for Levels A or AA. Level A errors were rated serious or critical to user impact, while all Level AA were rated serious. The disabilities affected by non-conformance to web accessibility standards were blind, cognitive, colorblindness, deaf, deafblind, low vision, and mobility. Several errors (block bypass, form label, frame title, image text, link name, and th data cells) also violated Section 508 of the Rehabilitation Act (29 U.S.C. § 794d) (Deque University, 2021; U.S. Access Board, 2001; U.S. Access Board, 2021).

Similar to research by Panda and Chakravarty, the free browser-based accessibility tools reported errors in all four WCAG 2.1 categories (perceivable, operable, understandable, and robust). Manual error testing concluded all but one issue type reported were properly identified. Lighthouse incorrectly registered errors instead of warnings for hierarchical headings. Hierarchical headings were not specified as a requirement for WCAG compliance (W3C, 2021a). As with research by Ng, Acost-Vargas et al., and Zahran et al., manual evaluation was required to discern the accuracy of automated tool reports. Additional discrepancies were discovered in reporting. An incorrect error total was reported in one report provided by ARC Toolkit. The automatic assessment stated a total of 25 errors occurred in the L2 audit. The audit listed 24 errors. Another issue was proprietary Lighthouse scoring (Google Developers, 2021). The tool scored L4 at 84 in Google Chrome despite 31 errors and 91 in Microsoft Edge though L4 documented the highest number of error instances (21). For comparison, Lighthouse determined L5 had the largest quantity of issues (35) in Google Chrome and scored 63, and the second highest in Microsoft Edge (17) with a score of 59. The weighted average algorithm used by Lighthouse for internal ranking

may generate false confidence of WCAG conformance and failed to allow for comparison across tools, browsers, libraries, or internally by the libraries. Lighthouse and Accessibility Insights for the Web reported the highest percentage of identical errors (~88%) in Google Chrome and Microsoft Edge. Axe Accessibility recorded fewer matching errors with other tools. Compared to Lighthouse and Accessibility Insights for the Web, Axe Accessibility reported a sixty-four percent match rate in Google Chrome and seventy-eight percent in Microsoft Edge. ARC Toolkit rated the least similar, with identical numbers reported at a low twenty-three percent compared Lighthouse, Accessibility Insights for the Web, and Axe Accessibility.

Discrepancies were also found by accessibility tool, including tool availability by browser, same-tool evaluation by browser, and tool reports, hindering method assessment similar to research by Zahran et al. Browser availability limited the number of evaluations and comparisons by browser and tool, which directly affected the results of the study. ARC Toolkit was provided for Google Chrome only. Accessibility Insights for the Web and Lighthouse were available for Google Chrome and Microsoft Edge. Axe Accessibility was the only tool available for all three browsers (Google Chrome, Microsoft Edge, and Mozilla Firefox) and the only tool available to Mozilla Firefox. Reporting issues discovered in the accessibility tool through the only three-way browser assessment were the exclusion the video caption and aria allowed errors that were reported in Google Chrome. Another issue with the automated accessibility tools was the reports highlighted errors with WCAG rule information but excluded the conformance information on warnings and passing criteria. Assessment of false negatives or false positives was obstructed without the WCAG information; therefore, excluded from this study. Manual tests were performed on only identified errors for this reason.

CONCLUSION
The World Wide Web Consortium developed Web Content Accessibility Guidelines to support continuity in accessible designs and conformance to mandated disability regulations by U.S. law. Libraries invested in web accessibility were best prepared to assist virtually serviced communities. For automated and

manual assessments, knowledge of the WCAG success criteria, web languages, and disabilities was required. If the user did not hold the necessary knowledge or skillset to read or edit technical reports or languages, analyses and corrections would be practically impossible. Another barrier to conformance was if the content management system used for web design prevented code manipulation.

Future researchers were suggested to assess library accessibility through fewer tools and expanded manual evaluations. Accessibility Insights for the Web reports were based on a limited selection from axe core, which was developed for Axe Accessibility. Axe Accessibility was the only tool available on all three browsers (Microsoft, 2021). Due to the compared limited scope, Accessibility Insights for the Web could be eliminated and replaced in future studies with Axe Accessibility. Manual success criteria tested would expand to include all criteria tested by the automated tools for full report analyses. Future studies would yield greater results if the evaluation of manual-only testable regions was included and manual evaluation of all reported elements, including errors, warnings, and passes, were conducted for a comprehensive web accessibility report. Furthermore, persons afflicted with one or more of the tested impairments would add depth to the study (Schmutz, Sonderegger, and Sauer, 2017).

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