



**An Investigation into Accessibility and Usability Standards for
Individuals with Limb Loss: A Research-Based System Development
Study**

by

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DECLARATION

I, Jeffery Aideyan-Ohonba declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

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Abstract

Digital accessibility standards such as the Web Content Accessibility Guidelines (WCAG) are widely used to support inclusive design, yet questions remain about how effectively they address the real-world needs of users with motor impairments, particularly individuals with limb loss. The aim of this project was to investigate how well motor-relevant WCAG 2.2 Success Criteria support keyboard-based interaction for users with limb loss, and to explore whether additional evaluation approaches are required to capture practical motor accessibility outcomes.

To address this aim, a mixed-method accessibility evaluation was conducted across three websites with differing interaction complexity: a custom limb-loss recovery web application, the NHS website (nhs.uk), and Booking.com. WCAG-EM methodology was used to assess motor-relevant WCAG 2.2 Level A and AA Success Criteria, focusing on keyboard operability, focus management, bypass mechanisms, and target size. This standards-based evaluation was complemented by a motor-focused heuristic usability assessment, which examined interaction effort, user control, error recovery, and sustained keyboard use through representative task-based interaction.

The findings revealed clear differences in motor accessibility performance across the evaluated websites. The NHS website demonstrated consistently strong conformance and low motor burden, reflecting its largely linear interaction model and consistent design system. The custom web application showed partial conformance, with critical keyboard accessibility failures concentrated on a single complex page. Booking.com exhibited multiple motor accessibility barriers, including keyboard traps, unreliable focus visibility, and inefficient interaction patterns that prevented reliable task completion. While WCAG effectively identified technical accessibility failures, the heuristic evaluation exposed additional motor effort and usability challenges that were not fully captured through conformance testing alone.

The project concludes that WCAG 2.2 is necessary but not sufficient for evaluating motor accessibility for users with limb loss. Integrating motor-focused heuristic evaluation alongside WCAG conformance testing provides a more complete understanding of real-world accessibility and supports more inclusive design outcomes for complex web interfaces.

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1. Introduction

The digital world offers significant opportunities for individuals to access information, engage with services, and participate in society. However, for people living with physical disabilities such as limb loss, these opportunities can be limited by the way digital systems are designed. Without inclusive practices, many websites and applications remain difficult or even impossible to use for individuals who rely on assistive technologies or alternative interaction methods due to the loss of one or more limbs.

Accessibility and usability are two critical, interrelated concepts in the design of inclusive digital systems. Accessibility refers to the extent to which a system can be used by people of all abilities and disabilities, particularly those who rely on assistive tools such as screen readers, alternative input devices, or voice navigation. Usability, on the other hand, focuses on how effectively, efficiently, and satisfactorily a system can be used by its intended audience. While accessibility aims to remove barriers, usability ensures that the experience is intuitive and user-friendly; both are necessary for meaningful inclusion.

Several international standards and guidelines have been developed to support the creation of accessible digital systems, such as the Web Content Accessibility Guidelines (WCAG) [1], Accessible Rich Internet Applications (ARIA) specifications [2], and the overall work of the Web Accessibility Initiative (WAI) [3]. These standards offer best practices for making content perceivable, operable, understandable, and robust. However, many digital tools either fail to implement these guidelines fully or adopt a one-size-fits-all approach that does not account for the unique needs of specific disability communities, especially those with limb loss.

While accessibility is governed by formal standards such as the ones mentioned above, usability is typically guided by non-standardised best practices, such as Nielsen's 10 usability heuristics [4]. For individuals who have lost one or more limbs, the way they interact with digital interfaces can vary greatly depending on factors such as which limbs were lost, the number of limbs lost, and their stage in the recovery journey (pre-surgery, during rehabilitation, or post-surgery).

Despite the increasing focus on inclusive design, there remains limited research that focuses specifically on how accessibility standards apply to users with limb loss or whether these standards adequately support their interaction needs in real-world digital contexts.

Addressing this issue requires a closer examination of how existing frameworks can be adapted to the specific needs of this group. There is a recognised need to investigate how existing accessibility frameworks, informed by usability principles, might be adapted or applied to better serve users with limb loss. Understanding these challenges and exploring how such standards can be practically implemented may help bridge the divide between theoretical compliance and real-world usability.

Where the project idea came from?

This project is situated within a broader context of efforts to improve digital inclusion for individuals with limb loss. Organisations such as the Limbless Association (LA) [6], supported by charitable bodies including the VTCT Foundation [5], play a critical role in providing practical, emotional, and informational support to amputees across different stages of their recovery journey. As access to support services increasingly shifts toward digital platforms, the accessibility of these systems becomes a key factor in ensuring equitable access to information and care.

Despite the availability of established accessibility standards, there remains limited empirical research examining how effectively these standards support the specific interaction needs of users with limb loss, particularly in relation to motor accessibility and sustained keyboard-based interaction. Existing guidance often addresses accessibility at a general level, without considering how interaction effort, control, and recovery demands may vary for users with different forms of motor impairment.

This gap highlights the need for targeted investigation into how current accessibility standards are applied in practice, and whether they adequately support real-world interaction for users with limb loss. The present study responds to this need by examining motor-relevant WCAG 2.2 Success Criteria alongside usability-based heuristic evaluation, with the aim of identifying both technical and experiential accessibility challenges.

Aim and Objectives

The aim of this project is to investigate how effectively current digital accessibility standards, particularly WCAG 2.2, support the real-world accessibility needs of users with limb loss.

Research question

How well do existing digital accessibility standards support the real-world accessibility needs of users with limb loss?

Objectives

1. Analyse the suitability of existing digital accessibility standards for users with limb loss:

- Review and summarise WCAG 2.2 and ARIA, practices within the WAI guidelines.
- Evaluate the relevance of WCAG 2.2 Success Criteria to limb-loss-specific interaction challenges, highlighting potential gaps in supporting sustained motor interaction and effort.

2.Design and develop a prototype support system informed by accessibility standards and identified gaps, and prepare it for subsequent evaluation:

- Implement interface features informed by WCAG 2.2 conformance and established accessibility best practices.
- Adapt content delivery and interaction mechanics to accommodate different stages of recovery.
- Prepare the developed prototype for subsequent usability and accessibility evaluation

Report Structure

This report is organised into six main chapters. Chapter 1 introduces the context, motivation, and scope of the study, outlining the research aim, objectives, and question. Chapter 2 presents a review of relevant literature, examining digital accessibility standards, usability principles, and prior research related to motor accessibility and limb loss.

Chapter 3 describes the research methodology, including the evaluation framework, website selection, tools used, and procedures for WCAG 2.2 conformance testing and heuristic evaluation. Chapter 4 presents and discusses the results of these evaluations, comparing motor accessibility outcomes across the selected websites and synthesising findings from both assessment methods.

Chapter 5 concludes the report by summarising the key findings and offering recommendations for accessibility practice, evaluation approaches, and future research.

Chapter 6 provides a reflective account of the project, considering methodological decisions, learning outcomes, and insights gained through the evaluation process.

Supporting materials, including detailed evaluation results and heuristic summaries, are provided in the appendices.

2. Literature Review

2.1 Theoretical Foundations

2.1.1 Disability Models

Before diving into the concepts of accessibility, usability, and inclusive design, it is crucial to understand the foundational models that have shaped how disability itself is framed in society. These models, particularly the medical and social models of disability, not only influence public perception and policy but also inform how systems are designed, who they prioritise, and what forms of inclusion are considered valid.

2.1.1.1 Medical Model of Disability

The medical model of disability locates the “problem” of disability within the individual’s body or mind, framing impairments as abnormalities to be cured or normalised [7]. Coined by psychiatrist Dr. Thomas Szasz in the mid-1950s, it originally critiqued psychiatry’s pathologisation of human emotions and behaviours, treating them as diseases to be managed with medication rather than addressing stigma or social injustice. By the 1970s, this model had become the dominant paradigm for both mental and physical conditions: people with limb loss came to view medical treatments such as surgery, prosthetics, and therapy as instruments of normalisation. Under this model, disabled individuals are sorted into “normal” and “abnormal” categories, which denies them access to resources, curtails life opportunities, and strips away agency. Large-scale institutionalisation and segregation in special programs reinforced perceptions of inferiority, while a deficit-based diagnostic and therapeutic industry continually framed disability as a personal burden. Terminology such as “afflicted” or “suffering,” along with practices like forced sterilisation, eugenics, and genocidal policies, further entrenched the view that disabled lives are expendable. Although the medical model advanced certain treatments, it also cemented power imbalances, empowering professionals to define “normalcy” and marginalising disabled people in law, education, and daily life [7].

2.1.1.2 Social Model of Disability

In contrast, the social model of disability shifts the focus from individual impairments to the barriers erected by society [7]. Sparked by disability rights activism in the 1970s, most notably the 1975 manifesto of the Union of the Physically Impaired Against Segregation and sociologist Mike Oliver’s naming of the model, it asserts that disability is a constructed

phenomenon. Cultural norms, institutional practices, and inaccessible environments “disable” people more than their bodies or minds. Features of this model include identifying architectural, policy-based, and attitudinal obstacles; demonstrating how social expectations and economic systems can either disable or enable participation; and mobilising collective action through demands for accommodations, legislative reform, and cultural advocacy. By framing disabled individuals as a minority group entitled to equal rights, the social model empowers communities to dismantle oppressive structures and reshape societal attitudes [7].

Together, these models provide the conceptual lenses through which accessibility and usability must be understood. They lay the groundwork for interpreting design decisions, not as neutral acts, but as responses to broader ideologies about human difference. The following section builds on these foundations to examine how accessibility and usability have emerged within Human-Computer Interaction (HCI), directly influenced by assumptions and critiques embedded in these disability perspectives.

2.1.2 Accessibility & Usability

Accessibility and usability are closely related concepts within the field of Human-Computer Interaction (HCI), often treated as two sides of the same coin. According to Mosconi and Porta [8], Accessibility refers to the ability of all users, including those with disabilities, to access digital content and services, often by removing barriers through the use of assistive technologies or inclusive design choices [8]. Usability, on the other hand, focuses on how intuitively, efficiently, and satisfactorily users can interact with a system, once access has been established [8]. While accessibility aims to expand *who* can use a system, usability addresses *how* effectively and comfortably they can do so. Some scholars consider accessibility as a subset of usability, particularly when accessibility is framed as designing “effective, efficient and satisfying user interfaces for more people in more situations” [8]. The distinction also lies in their primary focus: accessibility often addresses physical, sensory, and motor limitations, whereas usability typically deals with cognitive aspects such as memorability, error management, and user satisfaction [8]. For instance, making subtitles large and legible would be an accessibility concern, while optimising line breaks for easier reading pertains to usability [8]. Unlike accessibility, which can often be validated with technical checks, usability requires deeper insights from HCI research, especially into how users think and behave [8]. As a result, improving usability tends to involve broader

knowledge drawn from psychology, ergonomics, and cognitive science, making it a more complex and user-centred challenge [8].

2.1.3 Design Theories

2.1.3.1 Universal Design

Universal Design is a concept introduced by Ronald L. Mace, an architect and designer who emphasised the importance of designing environments and products that accommodate the needs of all people, regardless of age, ability, or status in life. The approach emerged from earlier frameworks like barrier-free and accessible design, but builds on them with a more comprehensive view. Mace highlighted that removing a barrier for one person might inadvertently create a barrier for someone else, so a broader perspective is required to truly achieve inclusive design solutions. Universal Design is defined as “the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialised design” [9].

One of the most widely cited tools to explain this concept is the Seven Principles of Universal Design. These include:

- **Equitable Use:** Ensuring the design is useful to people with diverse abilities.
- **Flexibility in Use:** Accommodating a variety of preferences and abilities.
- **Simple and Intuitive Use:** Keeping the design easy to understand regardless of user experience or cognitive load.
- **Perceptible Information:** Communicating information clearly, regardless of sensory ability or environmental conditions.
- **Tolerance for Error:** Reducing hazards and the effects of accidental actions.
- **Low Physical Effort:** Enabling efficient and comfortable use with minimal fatigue.
- **Size and Space for Approach and Use:** Designing for a range of body sizes, postures, and mobility levels.

An example of Universal Design in action is Toyota’s approach to vehicle interfaces. They’ve standardised many car controls to be easily replaceable, allowing features like steering or acceleration to be adapted for different users with minimal extra cost, enhancing accessibility while maintaining affordability [9].

2.1.3.2 Inclusive Design

Inclusive Design is a term most commonly used in the UK, and it has been formalised in standards like the British Standard on Managing Inclusive Design. While it shares similarities with Universal Design, Inclusive Design introduces the idea of *reasonable possibility*, suggesting that products and services should be designed to be usable by as many people as reasonably possible, and without the need for specialised adaptation [9].

One working definition reads:

“The design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible on a global basis, in a wide variety of situations and to the greatest extent possible without the need for special adaptation or specialised design.”

The use of the word “*reasonably*” is key here. It sets Inclusive Design apart from other frameworks by recognising that full inclusion may not always be feasible in every design case. However, this contrasts with the stance of frameworks like the UN Convention on the Rights of Persons with Disabilities, which argues for accessibility as a non-negotiable right [9].

There’s also a more philosophical and evolving view of Inclusive Design, especially within design education. This view sees Inclusive Design not as a fixed checklist but as a continuously evolving process, shaped by a growing understanding of users’ needs and expectations. It focuses on designing beautiful and functional environments that serve everyone equally, regardless of age, gender, or disability [9].

2.1.3.3 User-Sensitive Inclusive Design/Design for Dynamic Diversity

User-Sensitive Inclusive Design (USID) emerged as a refinement of User-Centred Design (UCD), particularly in response to critiques that traditional UCD methods were not well-equipped to handle the diversity and complexity of user needs, especially those of disabled individuals. Researchers in Dundee argued that the inclusive and universal design goals may be overly ambitious or even counterproductive when applied to all products [9].

USID suggests modifying UCD by replacing “centred” with “sensitive.” This shift acknowledges that disability and user diversity, including communication difficulties, make it difficult to define a truly representative user sample. The term *inclusive* here is also used more

realistically, reflecting the limits of who can be reasonably included in a product's user group [9].

The concept of Design for Dynamic Diversity is discussed alongside USID. It is particularly relevant when designing interfaces for older adults, whose cognitive, physical, and sensory abilities often change over time. This approach emphasises the need to design with an understanding of this ongoing, individualised change in mind [9].

By grounding this work in Universal Design, Inclusive Design, and User-Sensitive Inclusive Design (including Design for Dynamic Diversity), this study establishes a conceptual framework for understanding and evaluating accessibility in relation to limb loss. Universal Design provides a broad aspiration toward solutions that are usable by the widest possible range of people, while Inclusive Design introduces a more pragmatic perspective by recognising real-world constraints and the need for reasonable accommodation. User-Sensitive Inclusive Design and Design for Dynamic Diversity further emphasise the importance of accounting for individual variation and change over time, which is particularly relevant for users navigating different stages of limb-loss recovery.

Rather than serving as a direct blueprint for system construction, these theories informed how accessibility was interpreted, assessed, and discussed throughout the evaluation. They shaped the criteria used to judge interaction quality, effort, and adaptability, and helped frame the analysis of where existing standards succeed or fall short in supporting users with limb loss. Together, these design theories provide a theoretical foundation that supports the project's focus on motor accessibility as a lived, evolving interaction experience rather than a purely technical compliance exercise.

2.2 Current State of Research

2.2.1 Accessibility Standards

2.2.1.1 Web Content Accessibility Guidelines (WCAG)

The development of accessibility standards has played a crucial role in guiding designers and developers towards more inclusive digital environments. The Web Content Accessibility Guidelines (WCAG), developed by the World Wide Web Consortium (W3C), define how to make web content more accessible to people with a wide range of disabilities, including visual, auditory, physical, speech, cognitive, and neurological impairments. WCAG is structured around four core principles, known as POUR: Perceivable, Operable, Understandable, and Robust.

In practice, *Perceivable* ensures that information can be detected by users through appropriate sensory channels; *Operable* requires that users can interact with all functionality, including through keyboard-based input; *Understandable* focuses on predictable and clear content and interaction behaviour; and *Robust* aims to ensure compatibility with assistive technologies across different platforms [1].

WCAG is designed to be technology-independent and can be evaluated using both automated and manual methods. However, despite being the global benchmark for accessibility, WCAG primarily focuses on whether access is technically possible rather than on how easy or comfortable interaction is in practice. This distinction is particularly important for users with physical impairments such as upper-limb loss, whose challenges often relate to sustained physical effort, control, and interaction efficiency rather than content perceivability alone.

A real-world example of WCAG application can be seen in accessibility audits conducted within the hospitality and travel sector, where organisations increasingly rely on WCAG 2.2 conformance to assess digital systems [10,11]. While such audits demonstrate growing industry commitment to accessibility, they also highlight a recurring limitation: achieving compliance does not necessarily guarantee that systems are practically usable for individuals with specific motor constraints, such as one-handed or prosthetic users.

To ensure accessibility can be achieved progressively, WCAG adopts a three-tier conformance model. Level A addresses the most basic accessibility barriers, Level AA introduces more usability-oriented requirements, and Level AAA represents enhanced accessibility features

that are often difficult to achieve universally [1]. The latest version, WCAG 2.2, introduces new criteria such as 2.5.8 Target Size (Minimum) and 2.4.11 Focus Not Obscured (Minimum) [1], reflecting increased attention to interaction design and alternative input use. While these additions represent progress, WCAG remains largely compliance-oriented rather than experience-focused.

Overall, WCAG provides a strong and evolving foundation for accessible design, but its effectiveness depends heavily on interpretation and implementation. For users with limb loss, technical conformance does not always translate into practical usability.

2.2.1.2 Accessible Rich Internet Applications (WAI-ARIA)

Complementing WCAG is the Accessible Rich Internet Applications (WAI-ARIA) specification, which focuses on improving accessibility within dynamic and interactive web applications. ARIA enables developers to add semantic roles, states, and properties to interface elements so that assistive technologies can better interpret complex components such as custom buttons, menus, and modal dialogs [2].

ARIA plays an important role in modern web development, particularly where native HTML alone is insufficient. However, incorrect or excessive use of ARIA can introduce accessibility problems, such as interfering with native keyboard behaviour or confusing assistive technologies [2].

For users with physical impairments, including those with upper-limb loss, ARIA can improve technical operability by supporting alternative input methods. However, ARIA primarily addresses how elements are exposed to assistive technologies rather than how physically demanding interactions are to perform. For example, ARIA may make a drag-and-drop control technically operable, but it does not ensure that the action can be comfortably completed using one hand or a prosthetic.

As a result, while ARIA strengthens accessibility at a technical level, it does not fully address the physical interaction challenges faced by some users. Examining how ARIA and WCAG operate together is therefore important when assessing whether current standards adequately support users with diverse motor needs.

2.2.1.3 Gaps in Accessibility Standards for limb-loss users

Although WCAG is widely used as the primary reference for accessible digital design, it does not fully capture the physical and interaction-based challenges experienced by users with limb loss. Accessibility evaluations often focus on whether criteria are met, rather than on how comfortable or efficient interaction is in practice.

Table 1 highlights how WCAG principles may fall short when applied to limb-loss-specific interaction challenges.

Table 1. WCAG Principles vs. Limb-Loss-Specific Interaction Issues

WCAG Principle	Relevant Guidelines / Intent	Potential Limitations for Limb-Loss Users	Example Scenario
Perceivable	Ensures content is perceivable through different sensory channels (e.g., text alternatives, captions).	Focuses on sensory access (seeing, hearing), not physical access or control.	A user can clearly see all page content, but interactive elements (like buttons or sliders) are too small or closely spaced to accurately tap using one hand or prosthetic input.
Operable	Requires that all functionality can be accessed via keyboard or assistive technologies.	Assumes users can easily perform input actions (e.g. using a keyboard or equivalent device). Limited consideration for	A drag-and-drop action or swipe gesture needs precise or sustained control, which can be

		one-handed, prosthetic, or adaptive control methods.	difficult with one-handed input.
Understandable	Ensures content and navigation are clear and predictable.	Doesn't consider that some users may need extra time or modified input methods to complete predictable tasks.	A form gives clear instructions, but the "submit" button times out or resets if not clicked quickly, making predictable steps frustrating for users entering data one-handed.
Robust	Ensures compatibility with assistive technologies across platforms.	Focuses mainly on software and device compatibility, not on hardware comfort or physical ease of use.	A web app is fully compatible with assistive software, but touch gestures required to perform key actions are difficult for users using a prosthetic or switch device.

This comparison demonstrates that a system can be technically accessible while remaining physically demanding or inefficient for users with upper-limb loss. As a result, compliance alone may not reflect real-world accessibility outcomes for this group.

These limitations suggest the need for complementary evaluation approaches that focus more directly on interaction effort and usability, rather than technical access alone.

2.2.2 Usability Frameworks (Nielsen's Heuristics)

Building on the gaps identified in current accessibility standards, this next section looks into heuristic evaluation as a complementary usability method. Heuristic evaluation provides a more hands-on way of assessing design quality and user experience by identifying potential usability issues early, whether or not the system meets formal accessibility criteria. Understanding its foundation, strengths, and limitations helps to show why it can be valuable when examining accessibility from a more practical and user-centred perspective, especially for users with specific physical interaction needs like limb loss

Foundational Basis

The concept of heuristic evaluation was first introduced as a practical usability inspection method aimed at improving user interface design without the heavy resource demands of formal or empirical testing. In their 1990 paper *Heuristic Evaluation of User Interfaces*, Nielsen and Molich explained that most real-world usability assessments at the time were conducted informally and lacked systematic structure, as developers often did not have the time or expertise for formal usability testing [12]. They proposed heuristic evaluation as a simpler, expert-based approach that could be performed by “looking at an interface and trying to come up with an opinion about what is good and bad about the interface,” guided by a concise set of usability principles rather than extensive checklists or formal standards [12]. Their initial framework included nine heuristics, such as “simple and natural dialogue,” “speak the user’s language,” and “provide feedback”, which were designed to capture the most common usability problems in software interfaces while remaining easy to apply in practice [12].

However, the development of these principles actually began earlier, in 1989, when Jakob Nielsen and Rolf Molich taught a user interface course at the Technical University of Denmark. Nielsen later explained that the first set of heuristics was created informally as a grading rubric for student projects, consisting of ten principles based on their professional judgment rather than empirical research [13]. This early version laid the foundation for the 1990 publication and for subsequent refinements of the method. In 1994, after conducting more systematic research and analysing large sets of usability problems, Nielsen revised and finalised the list of ten heuristics that have remained in use for over 30 years [13]. These updated principles, such as visibility of system status, user control and freedom, and recognition rather than recall, were developed to maximise explanatory power across a wide range of user interfaces.

According to Nielsen, their durability stems from the fact that they address fundamental mismatches between humans and machines rather than specific technologies, which has allowed them to stay relevant across decades of evolving digital systems [13].

The Ten Usability Heuristics

Jakob Nielsen's ten usability heuristics are widely recognised as foundational guidelines for designing intuitive and user-friendly interfaces. They provide general principles rather than strict rules, making them adaptable across different types of systems and devices [4].

1. **Visibility of System Status:** The system should always keep users informed about what's going on through timely and appropriate feedback. This helps users understand the results of their actions and feel confident in what's happening.
2. **Match Between the System and the Real World:** Interfaces should use language, symbols, and structures that feel natural and familiar to users instead of relying on technical jargon or abstract terms.
3. **User Control and Freedom:** Users should have a way to undo mistakes or exit unwanted actions easily, which helps reduce frustration and gives them a sense of control.
4. **Consistency and Standards:** Designs should follow established conventions so that users don't have to relearn how things work every time they use a new product.
5. **Error Prevention:** The best designs prevent problems before they happen, for example by confirming risky actions or removing error-prone conditions altogether.
6. **Recognition Rather than Recall:** Information and options should be visible so that users don't have to rely on memory to complete tasks.
7. **Flexibility and Efficiency of Use:** Systems should support both new and experienced users by offering shortcuts or customization options that speed up interactions for those who know what they're doing.
8. **Aesthetic and Minimalist Design:** Interfaces should be clean and focused only on essential information, avoiding clutter that might distract users.
9. **Help Users Recognize, Diagnose, and Recover from Errors:** When errors occur, the system should clearly explain the problem in plain language and offer suggestions for fixing it.

10. Help and Documentation: Even though good design should be self-explanatory, accessible help content or concise documentation can support users when they need extra guidance.

Together, these heuristics capture the most common principles behind good interaction design. They are intentionally broad, which allows them to be applied to a wide range of technologies and user needs [4].

Advantages, Limitations, and Outlook for the Future

Nielsen's usability heuristics have long been recognised for their efficiency and practicality in identifying interface design problems early in the development process. Compared to more resource-intensive techniques like user testing, heuristic evaluation offers a quicker and often cost-effective approach to uncovering major usability flaws [14]. For example, studies have shown that heuristic evaluations can successfully predict a significant portion of the usability problems that would later surface during usability testing. In one study involving dental computer-based patient records, heuristic evaluation identified around 50% of the usability problems found in user tests, which demonstrates its potential value in early system design [14]. This ability to highlight key issues before full-scale testing makes it an attractive method for developers and researchers who need rapid feedback on design quality.

However, while heuristic evaluation is strong in efficiency and early detection, it does have its limitations. The same study noted that many heuristic violations only suggested potential problems rather than directly predicting specific usability failures [14]. This means that while the method can indicate areas that might cause trouble, it doesn't always provide detailed insight into how or why those issues occur. Additionally, the effectiveness of heuristic evaluation can depend heavily on the evaluator's expertise, and combining it with other usability methods such as empirical user testing, often yields more comprehensive results [14]. In other words, heuristic evaluation works best as part of a multi-method approach rather than a standalone technique.

Looking towards the future, Nielsen's ten heuristics are still widely respected, but researchers have started questioning whether they remain fully suited to modern technologies and interfaces [15]. Since the original heuristics were developed based on systems from before 1994, some argue that they may not fully capture the complexity of current digital

environments like Web 2.0 or emerging technologies [15]. The need for updated or domain-specific heuristics is becoming more apparent, particularly as technology continues to evolve rapidly. Moreover, some researchers suggest that heuristic evaluation could be strengthened by integrating more empirical data and encouraging collaboration between heuristic and user-based testing [15]. Overall, while Nielsen's heuristics continue to provide a strong foundation for usability evaluation, their future likely lies in adaptation, fine-tuning them to fit new contexts and technological developments while maintaining their core simplicity and usefulness.

2.2.3 Summary and Link to Evaluation Frameworks

This review highlights that while accessibility standards such as WCAG and ARIA are essential for establishing a baseline of technical accessibility, they do not fully address the practical interaction challenges faced by users with limb loss. Compliance-focused evaluation can overlook issues related to physical effort, sustained interaction, and recovery from errors, all of which are central to real-world usability for this group.

This reinforces the idea that accessibility shouldn't just be about ticking boxes for compliance, but about how easy and effective a system actually is to use. It highlights why it's important to look beyond checklist testing and include usability-focused approaches that reflect people's real experiences. In this sense, exploring accessibility evaluation frameworks and usability-based methods can help uncover where current standards fall short and how they might be improved. This naturally leads into the next section, which looks at how different frameworks can be used to assess both compliance and real-world usability.

2.3 Accessibility Evaluation Methods

After identifying limitations in current accessibility standards, it is also important to consider how accessibility is evaluated in practice. Evaluation methods provide ways to check whether websites meet accessibility requirements and whether users can actually complete tasks using different interaction methods.

In general, accessibility evaluation is approached through three main methods: automated testing, manual (expert) testing, and user testing. Automated tools scan code and rendered

pages for rule-based WCAG issues, manual testing involves structured human inspection and interaction testing (often using assistive technologies or keyboard-only use), and user testing observes real users to identify practical barriers that other approaches may miss. Because each method captures different kinds of issues, accessibility work often benefits from combining approaches rather than relying on one method alone.

Beyond these traditional approaches, some researchers and practitioners also use usability-based methods such as heuristic evaluation to complement accessibility assessments. This is particularly relevant for motor impairments such as limb loss, where the main barrier may not be whether interaction is technically possible, but how much effort and control it requires in practice.

2.3.1 Automated Testing

Automated accessibility testing uses software to evaluate how well a website meets accessibility standards such as WCAG. Automated tools apply predefined rules to scan either source code or live pages and flag common accessibility problems. When evaluating web content, it can be useful to distinguish between technical content (HTML, scripts, and interaction logic) and natural information content (the visible text, media, and interface elements users interact with) [16].

Automated testing offers clear advantages in speed, consistency, and scalability, and it can support early detection during development. However, automated tools only detect a portion of real accessibility issues. One study reported that automated tools detect roughly 32.4% of accessibility problems, with the remainder requiring human inspection [17]. This limitation exists because many criteria depend on context and judgement (e.g., whether link text is meaningful, or whether content structure supports real navigation). Automated testing can also produce false positives or false negatives and cannot reliably assess interaction comfort for specific disability groups [17]. For these reasons, automated testing is best treated as a baseline rather than a complete evaluation method.

A range of tools support automated WCAG checks, including axe DevTools, WAVE, Google Lighthouse, and Siteimprove. The W3C maintains an up-to-date list of accessibility evaluation tools to support tool selection [18]. These tools are useful for identifying common violations

quickly, but still require manual validation and follow-up testing for more complex or context-dependent issues.

2.3.1.1 axe DevTools Extension(Deque Systems)

The axe DevTools Extension, developed by Deque Systems, is one of the most popular browser-based tools for automated accessibility testing. It integrates directly into browsers like Chrome and Firefox, allowing developers to scan live web pages for accessibility issues in real time. The tool supports multiple versions of the Web Content Accessibility Guidelines (WCAG 2.0, 2.1, and 2.2) and provides detailed, easy-to-read reports that include issue descriptions, screenshots, and practical suggestions for fixing each problem [18].

One of the main advantages of the axe DevTools Extension is that it supports automated, semi-automated, and manual accessibility checks directly within the browser. Deque describes it as offering “superior automated accessibility testing,” powered by a combination of rule-based analysis and computer vision to help identify issues more accurately and reduce false positives [19]. It’s also very beginner-friendly, no deep accessibility training is needed to start using it. The in-product guidance explains each issue in plain language and gives step-by-step advice on how to fix it [19].

That said, axe DevTools Extension can’t test everything on its own. Like other automated tools, it’s great for detecting technical accessibility problems such as missing alt text, poor colour contrast, or incorrect ARIA usage, but it still requires human input to review more subjective issues, like whether interactive elements are comfortable to use for someone with limited dexterity [16], [17]. Still, its combination of accuracy, ease of use, and browser integration makes it one of the most effective tools for conducting quick and reliable WCAG-based accessibility checks.

2.3.1.2 WAVE (WebAIM)

WAVE, developed by WebAIM, is one of the most widely used accessibility evaluation tools for identifying and fixing issues on web pages. It’s designed to help developers and QA teams make their content more accessible by providing clear, visual feedback directly within the browser. One of WAVE’s key strengths is its user-friendly interface, which overlays icons on the evaluated page to show where accessibility issues occur. For instance, red icons mark

errors, yellow highlight alerts, green indicate accessibility features, and light blue outline structural elements. This visual approach makes it easier to understand what each issue means in context and how it affects the user experience [17].

The WAVE suite includes a range of tools beyond the browser extension. The online WAVE tool allows users to test any public web page by entering its URL, while the Chrome, Firefox, and Edge extensions make it possible to check password-protected or dynamic content directly within the browser. For large-scale or enterprise-level testing, the WAVE API and Testing Engine can be integrated into development pipelines or CI/CD systems, allowing automated accessibility checks across multiple pages or secure environments. WAVE also provides the Accessibility IMpact (AIM) Report, which combines automated results with expert manual testing to assess a site's accessibility score and identify areas that most affect users with disabilities [20].

What sets WAVE apart from many other automated tools is its philosophy of combining automation with education. Rather than just listing technical violations, it aims to teach developers about accessibility by explaining the real-world implications of each issue and encouraging human evaluation to confirm results. However, like other automated tools, WAVE still relies on human judgment to assess complex or contextual issues that automation alone can't capture [20].

2.3.1.3 Google Lighthouse

Lighthouse is an open-source, automated tool developed by Google that helps improve the overall quality of web pages by running audits across several key areas, including performance, accessibility, SEO, and best practices. It can be run directly in Chrome DevTools, from the command line, or as a Node module, making it easy to use at different stages of development. Once given a URL, Lighthouse performs a series of automated checks and then generates a detailed report showing how well the page performed in each category. For accessibility, the report highlights detected issues, provides explanations of why they matter, and links to documentation that shows how to fix them [21].

One of Lighthouse's biggest strengths is how seamlessly it fits into existing development workflows. Because it's built into the Chrome browser, developers can test any page, whether

it's live, in development, or behind authentication, without needing additional setup. The tool evaluates content against WCAG guidelines and produces an overall accessibility score, along with actionable recommendations for improvement. This score helps teams quickly gauge accessibility progress over time and spot regressions when used in combination with Lighthouse CI, which allows continuous auditing across deployments [17], [21].

Overall, Lighthouse is widely recognised for being fast, easy to use, and well-integrated into developer tools. However, while its automated checks are useful for catching common accessibility issues, it still faces the same limitation as other automated tools: it can't interpret context or assess the usability of content for different disability groups. As such, its results are best used as a starting point for further manual or heuristic review [17], [21].

2.3.1.4 SiteImprove

Siteimprove is an online accessibility evaluation platform designed to help developers and content creators identify, understand, and fix accessibility issues directly within their workflow. It evaluates web pages against WCAG levels A, AA, and AAA, making it suitable for both basic and advanced compliance reviews. The tool can be used either through its browser extension or as part of the wider Siteimprove platform, which integrates accessibility checks with analytics and content management systems [17].

The Siteimprove Accessibility Checker browser extension allows users to review any webpage, including password-protected or dynamic pages, entirely within their browser. It instantly highlights accessibility issues, explains their potential impact on visitors, and provides practical recommendations for fixing them. The extension also supports checks for visual design best practices, such as colour contrast, heading structure, focus indicators, and form labelling. Additional tools simulate different types of colour blindness to help designers understand how visual elements appear to users with varying visual conditions [22].

According to recent research, Siteimprove stands out for its ability to categorise detected issues by severity and responsibility, linking each one to the relevant WCAG success criterion and providing direct access to source code through browser developer tools. This structured approach not only supports technical remediation but also helps prioritise the most critical accessibility barriers first. Siteimprove's reporting and analytics capabilities further support

teams in tracking progress over time and maintaining continuous accessibility improvements [17].

Overall, Siteimprove combines practical, in-browser convenience with structured, standards-based evaluation. While it still relies on automated detection and therefore cannot replace expert review, its visual feedback and actionable guidance make it a useful tool for both quick accessibility checks and ongoing monitoring during the development process [17], [22].

As seen from the evaluation of automated testing and its tools, automated methods play an essential role in quickly identifying accessibility issues and supporting early compliance checks. However, they cannot fully replace human expertise, especially for assessing context, interaction design, or usability from a disabled user's perspective. The next section therefore looks at manual testing, which complements automation by addressing the more complex or subjective aspects of accessibility that tools alone often miss.

2.3.2 Manual (Expert) Testing

Manual accessibility testing involves direct human inspection of a website against standards such as WCAG. In practice, this includes reviewing page structure and interaction behaviour, and often involves using assistive technologies or keyboard-only navigation to simulate real-world interaction and identify barriers automated tools miss.

The key advantage of manual testing is that it captures context. Unlike automated tools, human evaluators can assess issues that depend on meaning and interaction behaviour, such as whether focus order makes sense, whether controls behave predictably, or whether the interface supports task completion using keyboard-only input. Vigo et al. [23] note that automated tools cover only a fraction of accessibility criteria, with completeness rates reported between 14% and 38%, and that tools attempting broader coverage can introduce more false positives. This supports the idea that automation alone is not sufficient for reliable accessibility assessment.

That said, manual testing is time-consuming and depends on evaluator expertise. In practice, it is often conducted by general QA engineers rather than accessibility specialists, which can lead to inconsistencies when specific disability needs are not well understood [17]. Overall, manual testing complements automation by adding judgement, context, and interaction-level verification.

Even with automated and manual checks, some accessibility issues only surface when real users are involved. That's why many evaluators use user testing, which the next section explores in more detail.

2.3.3 User Testing

User testing refers to evaluating the accessibility of a website or digital system by observing real users, particularly people with disabilities, as they attempt to complete tasks or interact with the interface. While accessibility evaluation often focuses on checking conformance to standards like WCAG, involving real users provides a different type of insight: it helps reveal how a system actually works in practice and uncovers usability barriers that automated or expert reviews might miss [24]. According to W3C, evaluating with users exposes issues that conformance checking alone cannot detect, especially those related to interaction, comprehension, and the fit between assistive technologies and web content [24].

Strengths of User Testing

Studies consistently highlight the value of involving users in accessibility evaluations. User testing provides insight into users' genuine needs, the challenges they face, their mental models, and how they interact with digital content in real contexts [25]. It also helps evaluators understand how accessibility depends on the technical environment of use, such as the user's hardware, browser configuration, assistive technologies, or AT settings, which automated tools cannot simulate [25].

Research shows that involving users can lead to more informed design decisions by identifying opportunities for improvement, helping prioritise accessibility issues, and illustrating the real-world impacts of common barriers [25]. User input is also highly detailed, objective, and often more cost-effective than relying solely on experts for assessments that require human judgment [25].

W3C further notes that working with users helps evaluators understand where issues originate, whether from incorrect markup, browser behaviour, assistive technology limitations, or general usability problems that affect all users, not just people with disabilities [24].

Limitations of User Testing

Despite its strengths, user testing also has limitations. One of the most common challenges is representativeness. Many studies involve small or uneven samples that fail to capture the diversity within disability groups, whether in terms of impairment types, socio-economic background, digital skills, or familiarity with assistive technologies [25]. As a result, findings cannot always be generalised to all users with disabilities.

There are also methodological constraints. User testing often focuses on short interaction periods and may not uncover issues related to long-term use, fatigue, or learning over time [25]. It also does not reliably detect underlying code-level accessibility problems, such as missing heading structure, that automated or manual inspections can identify more efficiently [25].

Practical challenges further add to the complexity. User testing requires more time and resources than automated or expert-based methods. Recruiting participants with disabilities can be difficult, and logistics such as navigation to testing sites, configuration of assistive technologies, or setting up recording equipment can create barriers to smooth testing sessions, especially when working with personal devices or unfamiliar AT settings [25].

Combining User Testing With Standards-Based Evaluation

W3C stresses that user testing alone cannot determine whether a website is accessible. Because individual users only represent a small portion of the broader disability community, and because user testing often focuses on specific tasks, it must be paired with WCAG conformance checks to ensure consistent coverage of technical requirements [24].

User testing is therefore most effective when used alongside automated scans and manual expert reviews. This combined approach enables evaluators to identify both technical accessibility barriers and the practical, lived-experience issues that affect real users [24].

In summary, user testing offers deep, contextual insight into how people with disabilities interact with digital systems, highlighting barriers that other methods often miss. However, its limitations in scope, representativeness, and practicality mean it cannot stand alone. Instead, it complements automated and manual evaluation by grounding accessibility assessment in real user experience. The next section explores frameworks that combine these

different evaluation approaches to provide more robust and comprehensive accessibility assessments.

2.3.4 Hybrid/Framework Approaches

Because automated, manual, and user-based methods each capture different issues, hybrid approaches are commonly used in accessibility practice. Hybrid approaches combine methods in a structured workflow to improve reliability and transparency, without requiring that every method be used in every context.

A widely used framework is the WCAG Evaluation Methodology (WCAG-EM) developed by W3C. WCAG-EM provides a structured process for evaluating websites against WCAG, including defining scope, exploring the site, selecting a representative sample, evaluating pages against WCAG criteria, and reporting results [26]. WCAG-EM does not introduce new requirements; it standardises how WCAG is applied in practice [26].

Another example is the IBM Equal Access Toolkit, which supports accessibility across the development lifecycle by embedding accessibility across planning, design, development, and verification stages [27]. Although it is not a conformance methodology in the same way as WCAG-EM, it demonstrates how hybrid approaches can support continuous accessibility improvement rather than treating evaluation as a one-off activity.

Overall, hybrid frameworks address many of the limitations seen in using automated, manual, or user-based evaluation methods alone. Automated tools quickly identify common issues, manual checks uncover more context-dependent barriers, and structured frameworks like WCAG-EM ensure that these methods are combined in a repeatable and transparent way. As a result, hybrid methodologies offer a more complete and realistic picture of accessibility, especially for complex or dynamic websites where no single technique is sufficient.

Despite the strengths of automated, manual, hybrid, and user-based methods, accessibility evaluation often remains centred on WCAG rules. However, as identified earlier, WCAG compliance alone does not guarantee that a website is easy or efficient to use. This gap has led evaluators to incorporate usability-based techniques, such as heuristic evaluation, which the next section examines.

2.3.5 Usability-Based Evaluation (Heuristic Evaluation)

Although heuristic evaluation is not traditionally classed as one of the main accessibility testing methods, it is increasingly being used in situations where WCAG compliance alone does not fully capture the user experience. Earlier in the literature review, it was clear that people with limb loss often face barriers that WCAG does not explicitly cover, such as comfort, physical effort, and the ease of performing common interactions. These gaps suggest that accessibility should be assessed not only through technical conformance, but also through how usable and practical an interface actually feels to use.

Heuristic evaluation fits into this space. It is normally considered a subset of manual evaluation, because it involves an expert inspecting an interface and judging it against broad usability principles (heuristics) rather than specific WCAG success criteria. As discussed earlier when introducing Nielsen's heuristics, these principles help evaluators spot common design issues such as unclear feedback, inconsistent layout, or unnecessary effort during interactions, all of which can directly affect users with physical or motor-based accessibility needs.

It is also useful to distinguish heuristic evaluation from other evaluation methods. Automated tools focus on checking rule-based WCAG violations, which makes them fast but limited in what they can catch. User testing, on the other hand, involves observing real users, often with disabilities, as they carry out tasks, revealing lived barriers that cannot be predicted by inspection alone. Heuristic evaluation sits between these two. It does not involve users; instead, it relies on an expert's ability to anticipate likely usability problems using established principles. Because of this, it cannot replace user testing, but it offers a low-cost way to identify many interaction-level issues earlier and more consistently, especially when user recruitment is difficult or when participant samples risk being unrepresentative.

Heuristic evaluation is far from perfect; it depends heavily on the evaluator's experience, and different people may spot different issues, but it still offers a practical way to assess accessibility from a usability angle. Importantly, it doesn't replace user testing or WCAG checks. Instead, it complements them by highlighting interaction-level barriers that might only become visible much later if relying on user testing alone.

Overall, including usability-based methods like heuristic evaluation in accessibility work makes sense when the aim is to understand not just whether a system meets technical standards, but whether it is genuinely easy and comfortable to use. This is especially relevant for users with limb loss, where accessibility is closely tied to interaction effort, task efficiency, and physical ease, factors that WCAG and automated checks don't fully measure.

2.3.6 Summary and Relevance to Limb Loss

In summary, each evaluation method contributes something different: automation offers speed, manual testing adds accuracy, user testing shows real barriers, and heuristics highlight usability issues that WCAG doesn't fully capture. This matters for users with limb loss, whose interaction challenges are often missed by compliance checks alone. The next section uses these insights to define the evaluation approach for this study.

3. Research Methodology

3.1 Research Approach and Rationale

This project uses an evaluation-based research approach to examine how effectively current accessibility standards, particularly WCAG 2.2, support the needs of users with limb loss. Rather than studying user behaviour directly, the work focuses on whether standards-based evaluation captures the kinds of interaction barriers that affect people who rely on one-handed or reduced-dexterity input.

Alongside the evaluation, the project includes the development of a small custom web application designed with accessibility principles in mind. Its role is not to act as a full product case study, but to provide an accessibility-aware comparison point that can be evaluated using the same framework as the other websites.

This approach was informed by gaps identified in the literature review, particularly the idea that WCAG compliance can confirm technical access but may not reflect the practical usability demands that matter for motor impairments. For this reason, the study combines standards-based testing with an additional usability-focused lens to examine whether WCAG alone is sufficient in this context.

The specific evaluation methods, site selection criteria, and procedural steps are described in the sections that follow.

3.2 Evaluation Framework Selected

This study adopts a hybrid evaluation framework combining automated WCAG testing, manual expert review, and a usability-based heuristic evaluation. The literature review highlighted that no single method provides a complete picture: automated tools are fast but limited in coverage; manual checks capture context but take time and expertise; and user testing provides the strongest real-world insight but was not feasible within the constraints of this project.

To structure the process, the study follows the core steps of the WCAG Evaluation Methodology (WCAG-EM). WCAG-EM provides a clear, step-by-step approach for defining

scope, exploring a website, selecting a representative sample, evaluating against WCAG criteria, and reporting findings.

Rather than implementing WCAG-EM in full, this project adopts its core structure to ensure the evaluation is transparent, replicable, and grounded in established accessibility auditing practice.

Defining the Scope: WCAG Level and Success Criteria Selection

Following WCAG-EM Step 1 (“Define the Scope”), this study uses WCAG 2.2 Level AA as the target benchmark, as Level AA is widely treated in practice as a baseline expectation for public-facing websites.

However, the evaluation does **not** attempt to determine full WCAG conformance. Full conformance would require assessing every Success Criterion across the full site scope. Instead, this project uses a scoped WCAG-based benchmark focused on Success Criteria most relevant to motor accessibility, aligned with the aim of evaluating how well WCAG supports users with limb loss.

This scoped criteria set is not intended to replace WCAG or redefine compliance. WCAG remains the foundation for accessibility evaluation, and a full evaluation must address all disability categories and criteria. The narrowed selection in this project should therefore be understood as a focused lens used to examine motor accessibility in more detail. It does not capture non-motor barriers (e.g., visual or cognitive accessibility), which remain important but outside this project’s scope.

Success criteria were therefore selected based on:

- direct relevance to motor interaction (e.g., Target Size, Pointer Cancellation, Keyboard Operability).
- Evidence from the literature demonstrating frequent motor-related failures.
- The limb-loss interaction challenges identified in the earlier WCAG-limb-loss comparison table.

For this project, a website is considered to satisfy the motor-accessibility benchmark if it meets all selected WCAG 2.2 level A and AA success criteria associated with motor interaction.

A full list of the selected criteria, including descriptions and their relevance to limb-loss users, is provided in [Appendix A](#) (Table 2).

This targeted approach aligns with WCAG-EM's allowance for scoped evaluations when clearly documented and tied to the purpose of the assessment.

Rationale for Automated + Manual WCAG Checks

As demonstrated in the literature review, automated tools detect only a subset of accessibility barriers. Vigo et al. report that tool coverage can be as low as 14–38% of success criteria, and automated outputs can include false positives or miss context-dependent issues [23]. Manual inspection is therefore essential for criteria that depend on interaction behaviour, meaning, or context, such as focus handling, keyboard traps, and whether core tasks can actually be completed using keyboard-only input. For this reason, automated and manual checks were combined as the baseline WCAG evaluation method.

Rationale for Heuristic Evaluation

The literature review also showed that WCAG compliance alone does not guarantee a website is easy or comfortable to use, especially for users with limb loss who may rely on one-handed interaction, reduced precision, or compensatory strategies. The ACM study further emphasised that guidelines capture only about 50% of the accessibility problems encountered by real users, meaning that compliance testing leaves many practical barriers unexamined [23].

To address this gap, the framework incorporates heuristic evaluation as an additional layer. Heuristic evaluation is not a replacement for user testing, but it provides a structured way to assess usability issues, such as unnecessary effort, poor feedback, or inefficient task flows that are especially relevant for motor-based impairments. Including heuristics therefore allows the study to examine how accessible a website feels to use, not just whether it satisfies WCAG success criteria.

Why User Testing was Not included

Although user testing with participants who have limb loss would offer valuable insights, it is outside the scope of this project for several reasons:

- **Ethical and safeguarding considerations:** recruiting participants with recent or long-term limb loss would require formal ethical approval, risk management, and additional support mechanisms.
- **Risk of negative user experience:** evaluating websites that may be poorly designed could place participants in frustrating or emotionally difficult situations, raising ethical concerns.
- **Time constraints:** obtaining clearance, recruiting participants, and conducting moderated sessions is not feasible within the project timeline.
- **Representativeness issues:** small samples may not reflect the wide range of limb-loss experiences, as noted in multiple user-testing studies reviewed earlier.

Given these constraints, heuristic evaluation provides a practical alternative for exploring usability challenges without subjecting vulnerable participants to potentially inaccessible or uncomfortable interfaces.

How the Framework Aligns With Project Aims

This hybrid WCAG-EM-structured framework directly supports the project's goal: to assess how well current accessibility standards, especially WCAG, reflect the needs of users with limb loss, and whether additional usability-based perspectives are required to address gaps that WCAG alone may not cover.

By combining automated testing, manual WCAG review, and heuristic evaluation, the framework:

- reflects recommended best practice in accessibility evaluation literature
- addresses the known limitations of guidelines-only assessment
- focuses directly on the interaction challenges associated with motor impairment and limb loss

The next section describes the website selection process.

3.3 Website Selection Process

This study uses WCAG-EM as the structural basis for evaluation. Website selection forms part of WCAG-EM Step 1 (“Define the scope”) and is informed by Step 2 (“Explore the Website”), which recommends selecting sites that are relevant to the evaluation purpose and likely to reveal meaningful accessibility outcomes.

Because the aim is to examine how well current standards support users with limb loss, selected websites needed to:

- represent realistic, everyday digital interactions,
- span different types of online services,
- expose a range of motor-accessibility demands, and
- include at least one example designed with accessibility principles in mind.

Following these criteria, three websites were selected:

3.3.1 Custom Limb-Loss Recovery Web Application

URL: <https://delightful-island-079d50603.2.azurestaticapps.net/>

This web application was designed using accessibility principles and universal/inclusive design ideas, and focuses on staged recovery content relevant to limb loss. It serves as:

- a purpose-built resource that reflects the limb-loss context,
- and an accessibility-aware comparison point against mainstream sites

Because it was designed with reduced-effort interaction in mind, it provides a useful contrast for examining whether WCAG captures motor interaction needs adequately.

3.3.2 NHS Website (Public Sector / Healthcare)

URL: <https://www.nhs.uk/>

The NHS website was selected as a public-sector case study due to its role in healthcare access. Limb-loss users may rely on it for surgical information, rehabilitation guidance, prosthetics services, physiotherapy, mental health support, and long-term follow-up. It is also a large and structured platform, making it useful for evaluating keyboard navigation, focus behaviour, and interaction reliability on high-stakes public information pages.

3.3.3 Booking.com (Commercial / Service-Based Website)

URL: <https://www.booking.com/>

Booking.com was selected as the commercial example due to its global popularity and its interaction-heavy design. The site requires users to engage in tasks that are often challenging for individuals with motor impairments, such as:

- selecting small calendar dates,
- adjusting sliders and filters,
- navigating dense layouts,
- completing multi-step booking workflows,
- using complex forms, and
- interacting with tightly packed controls.

These characteristics make Booking.com an ideal candidate for identifying whether WCAG Success Criteria adequately capture the interaction demands faced by users with limb loss. Commercial websites like this are also relevant because people with limb loss routinely use them for everyday tasks, such as booking travel for medical appointments, family visits, or rehabilitation events.

3.3.4 Selection Strategy Summary

The chosen websites collectively provide:

- an accessibility-aware benchmark (the custom app),
- a public-sector, high-stakes information source (NHS.uk)
- a complex commercial service with dense interaction (Booking.com).

This aligns with WCAG-EM's focus on selecting a representative but manageable sample rather than attempting exhaustive whole-site evaluation.

The next section outlines the tools and resources used to conduct the evaluation.

3.4 Tools and Resources

This section outlines the tools and resources used. Tool selection was informed by the literature review, including findings from a 2025 IEEE study comparing automated tools for coverage and false positives [17]. The aim was to use a small set of widely adopted tools with complementary strengths.

3.4.1 Automated Accessibility Testing Tools

Three automated tools were used: axe DevTools, WAVE, and Google Lighthouse. These were selected because they are widely used in practice and provide complementary outputs.

- **axe DevTools:** used as the primary scanner due to strong rule coverage and low false positives reported in comparative research.
- **WAVE (WebAIM):** used for visual, in-context feedback on structure, labels, and ARIA-related patterns.
- **Google Lighthouse:** used for quick benchmarking and high-level issue summaries.

Together, these tools provide:

- rule-based precision (axe),
- visual and structural context (WAVE),
- and consistent baseline scoring (Lighthouse).

3.4.2 Manual Evaluation Resources

Manual WCAG checks will be carried out using:

- WCAG 2.2 documentation and technique guidance,
- Chrome DevTools (for inspecting HTML and ARIA attributes where relevant),
- Keyboard-only navigation as the primary interaction baseline.

3.4.3 Heuristic Evaluation Resources

The heuristic evaluation uses Nielsen's heuristics, interpreted through a motor-impairment lens.

A structured template was used to record:

- The heuristic/task group,

- Task context
- Observation (behaviour-based),
- And motor impact level (None/Low/Moderate/High).

3.4.4 Technical Setup

- Browser: Google Chrome (latest version)
- Extensions: axe DevTools, WAVE, Lighthouse (built-in)
- Device: laptop
- Operating System: macOS
- Recording: WCAG-EM Report Tool + heuristic tables in appendices

With the tools and resources defined, the next step is to outline how each of them will be applied during the evaluation. The following section sets out the step-by-step procedure used for automated testing, manual WCAG checks, and heuristic inspection, ensuring that the methodology is transparent and replicable.

3.5 Evaluation Procedure/Test Plan

The evaluation procedure follows WCAG-EM's structure within the hybrid framework. The steps below describe how automated testing, manual WCAG inspection, and heuristic evaluation were carried out for each website.

Use of the WCAG-EM Report Tool

All WCAG-related findings were recorded using the WCAG-EM Report Tool. The tool does not perform testing itself; it provides a structured format for documenting:

- evaluation scope and selected WCAG 2.2 criteria,
- the representative pages evaluated,
- automated tool outputs,
- manual inspection results,
- and summary conclusions.

This supported consistent reporting and ensured results mapped clearly to the motor-relevant Success Criteria.

Selection of Representative Pages (WCAG-EM Steps 2–3)

Following WCAG-EM Step 2-3, three pages were selected from each website to reflect core tasks and interaction patterns.

Custom Limb-Loss Recovery Web Application

1. Home Page
2. Article Repository page
3. Individual Article Page

Reasoning: These pages represent navigation, browsing/filtering, and detailed content interaction.

NHS Website (nhs.uk)

1. Home Page
2. Health A–Z Index
3. Amputation Information Page

Reasoning: These pages include high-traffic navigation patterns and health information relevant to limb-loss users.

Booking.com

1. Home Page (search interface)
2. Search Results Page
3. Property Details Page

Reasoning: These pages include interaction-heavy tasks (search, filtering, navigation, modal interactions)

3.5.1 Automated WCAG Testing Procedure

Automated evaluation was conducted using axe DevTools, WAVE, and Google Lighthouse for each selected page in Google Chrome under:

- Desktop viewport
- Default zoom level
- Browser extensions enabled
- Tests run twice where relevant:
 - Default load state (no interaction)
 - Expanded interaction state (e.g., open menus, expanded filters)

Procedure:

1. Open webpage in Chrome with axe and WAVE enabled.
2. Run axe DevTools scan and record issues and mapped WCAG criteria
3. Run WAVE and record key structural/ARIA and contrast outputs
4. Run Lighthouse accessibility audit and record score + flagged items
5. Store automated outputs for later consolidation into WCAG-EM

Automated results were used as a baseline and to guide manual inspection.

3.5.2 Manual WCAG Evaluation Procedure

Manual evaluation focused on the selected motor-relevant WCAG 2.2 Level A and AA Success Criteria relevant to motor impairments (Appendix A). Keyboard-only interaction was used as the primary baseline input method, reflecting common interaction methods used by people with limb loss and other motor impairments. Each page was inspected using the steps below.

1. Keyboard-Based Interaction

Pages were navigated using:

- Tab/Shift + Tab
- Enter/Space

- Arrow keys (where supported)

Recorded observations included:

- focus visibility and focus order behaviour,
- presence of keyboard traps
- inaccessible or skipped controls,
- and whether core tasks could be completed by keyboard.

2. Inspection Using Chrome DevTools

DevTools was used to confirm or explain behaviours observed during interaction (e.g., labels, roles, ARIA patterns), rather than as a standalone conformance method. Checks were applied where relevant to the selected criteria and observed behaviours.

3. Task-Based Interaction Testing

Representative tasks were performed per page (e.g., search, open menus, adjust filters, interact with common controls). Outcomes were recorded in terms of whether interaction was possible and whether criteria requirements were met.

4. Documentation

Findings were recorded during testing and consolidated into the WCAG-EM Report Tool, with screenshots and expanded notes stored for appendices.

3.5.3 Heuristic Evaluation Procedure

The heuristic evaluation applied six motor-relevant task groups (H1–H6) derived from Nielsen’s heuristics and interpreted through a motor-impairment lens. Representative tasks were performed on each sampled page using keyboard-based interaction.

Procedure

1. Perform representative keyboard-based tasks per page.
2. Record behaviour-based observations linked to motor burden (e.g., loss of focus visibility, excessive repetition, difficulty exiting states).
3. Record findings with task context and motor impact level (None/Low/Moderate/High).
Formal severity scoring was not applied; instead, emphasis was placed on whether issues

increased physical effort, impeded task completion, or reduced user control for individuals with limb loss.

4. Synthesise page-level findings into website-level motor impact summaries for cross-site comparison.
5. Compare heuristic findings with WCAG results to identify overlaps and gaps.

This heuristic evaluation provided an additional usability layer, enabling comparison between standards-based compliance and real-world motor interaction experience.

3.5.4 Data Recording and Organisation

All evaluation data were documented through:

- The WCAG-EM Report Tool, which served as the primary record of WCAG 2.2 findings,
- Structured WCAG summary tables presented in Appendix B,
- Heuristic evaluation tables (Appendix C), and
- Supplementary screenshots and observation notes used to support both WCAG and heuristic findings.

The next chapter presents the results and discussion, comparing WCAG and heuristic outcomes to evaluate how effectively WCAG alone addresses motor accessibility for users with limb loss.

4. Results and Discussion

4.1 Overview of Evaluation Outcomes

This section presents a high-level overview of the accessibility evaluation outcomes across the three evaluated websites: the Custom Limb-Loss Recovery Web Application, the NHS website, and Booking.com. The results are derived from the combined application of motor-relevant WCAG 2.2 conformance testing and a motor-focused heuristic evaluation, as detailed in Appendices [B](#) and [C](#).

Looking across the three websites, 2 out of the 3 evaluated platforms exhibited at least one high-impact motor accessibility issue when assessed using heuristic evaluation, while only the NHS website demonstrated consistently low or absent motor impact across all six heuristic task groups. Booking.com showed high or moderate motor impact in 3 of the 6 task groups, compared to 2 of 6 for the custom web application and 0 of 6 for the NHS website ([Appendix C](#)). High-impact findings were most commonly associated with keyboard operability (H1) and focus management (H2), which accounted for the majority of blocked or degraded interactions in more complex interfaces.

These quantitative patterns are reflected in the site-level WCAG and heuristics findings described below.

The NHS website demonstrated consistently strong performance across all sampled pages, with no WCAG failures related to motor accessibility and no heuristic findings indicating increased motor effort or loss of control. Keyboard-only interaction was reliable and efficient, supported by visible focus indicators, logical focus order, and effective bypass mechanisms such as skip links.

The Custom Limb-Loss Recovery Web Application exhibited partial conformance with motor-relevant WCAG 2.2 Success Criteria. While the home page and article repository page generally supported low-effort keyboard interaction, the individual article page introduced notable motor accessibility barriers. These included keyboard traps, skipped interactive elements, and reduced focus visibility, which together impeded task completion and increased interaction effort. Heuristic evaluation confirmed that these issues resulted in a

moderate to high motor burden during real-world use, despite otherwise clear content structure and predictable layout.

In contrast, Booking.com demonstrated systemic motor accessibility challenges across all sampled pages. Multiple WCAG failures related to keyboard access, focus visibility, and keyboard traps were identified, particularly in modal-based interactions and dense interface regions. Heuristic evaluation further revealed that even where interaction was technically possible, users were frequently required to perform excessive navigation, recover from loss of focus, or abandon tasks due to loss of control. These issues collectively produced a high motor burden and prevented reliable completion of core tasks using keyboard-only input.

Overall, the evaluation suggests that WCAG conformance alone does not always reflect the practical motor accessibility of interactive web systems. While the NHS website achieved both technical conformance and low-effort interaction, the Custom Web Application and Booking.com illustrate how increasing interaction complexity can introduce significant motor accessibility barriers. The combined use of WCAG and heuristic evaluation provided a more comprehensive understanding of both technical accessibility and real-world motor usability, forming the basis for the detailed results presented in subsequent sections.

4.2 WCAG 2.2 Motor-Relevant Evaluation Results

The WCAG 2.2 evaluation revealed clear differences in motor accessibility conformance across the three assessed websites, reflecting variation in interaction complexity, component behaviour, and task design.

The NHS website demonstrated consistently strong conformance across all motor-relevant Success Criteria evaluated. All sampled pages supported keyboard-only operation, logical focus order, clearly visible focus indicators, and effective bypass mechanisms. No keyboard traps, inaccessible components, or focus-management failures were identified. The evaluated pages therefore met WCAG requirements for uninterrupted keyboard access and predictable navigation within the sampled scope.

The Custom Limb-Loss Recovery Web Application showed mixed conformance outcomes. The home page and article repository page generally met motor-relevant WCAG requirements,

supporting keyboard navigation, predictable interaction behaviour, and adequately sized interactive targets. In contrast, the individual article page exhibited several WCAG failures, including inaccessible interactive components, disrupted focus order, reduced focus visibility, and the absence of a mechanism to bypass repeated content. These failures resulted in certain interactions not being reliably operable using keyboard-only input, indicating partial conformance across the evaluated sample.

In comparison, Booking.com exhibited multiple failures across key motor-relevant Success Criteria on all sampled pages. Keyboard traps within modal dialogs prevented users from exiting or completing tasks using keyboard-only input, resulting in failures of both keyboard accessibility and user control requirements. Inconsistent or missing focus indicators further disrupted keyboard navigation, leading to periods where focus position could not be visually determined. Although many individual controls met WCAG requirements for target size and labelling, several core task flows, most notably saving a property, were not reliably operable using keyboard-only input, representing direct functional barriers under WCAG 2.2.

Across all three websites, Success Criteria related to target size, labelling, and predictable input behaviour were generally well supported. In contrast, criteria associated with keyboard operability, focus management, and bypass mechanisms emerged as the primary differentiators in motor accessibility performance. Websites with simple, linear interaction models showed higher levels of conformance, while interfaces incorporating complex, stateful components were more likely to exhibit WCAG failures that directly impeded task completion.

Overall, these results demonstrate WCAG's effectiveness in identifying technical motor-accessibility failures where keyboard access, focus handling, or task-level operability is compromised. However, they also indicate that WCAG conformance alone does not capture all aspects of practical motor interaction, particularly in complex interfaces, a limitation addressed through the heuristic evaluation presented in the following section.

4.3 Heuristic Evaluation Results: Motor Accessibility in Practice

While the WCAG 2.2 evaluation assessed whether motor-accessible interaction was technically achievable, the heuristic evaluation examined how interaction design affected motor effort, user control, and efficiency during real keyboard-based use. Six motor-relevant heuristic task groups (H1–H6) were applied consistently across all sampled pages. In the results presented below, emphasis is placed on the task groups that produced meaningful and differentiating motor-accessibility outcomes across the evaluated websites, particularly where interaction patterns increased effort, reduced user control, or impeded task completion for users with limb loss.

4.3.1 Motor Effort and User Control Across Websites

Clear differences emerged in how effectively each website supported low-effort, controlled interaction. The NHS website consistently demonstrated no motor burden across all heuristic categories. Keyboard interaction was fully reliable, with strong bypass mechanisms, predictable focus behaviour, and linear content structures that minimised physical effort. As a result, users retained full control over navigation and task progression throughout all evaluated pages.

The Custom Limb-Loss Recovery Web Application exhibited a mixed motor accessibility profile. While most interactions supported low-effort use and predictable behaviour, a critical failure on the individual article page, specifically a keyboard trap within the “Share” control, resulted in a high motor impact under H1. This issue caused loss of user control and blocked task completion, demonstrating how a single interaction pattern can significantly degrade motor accessibility despite otherwise stable design.

In contrast, Booking.com consistently imposed a high motor burden in key interaction areas. Persistent keyboard traps within modal dialogs repeatedly blocked core tasks such as saving properties, resulting in high-impact failures under H1 across all sampled pages. These failures represent not just inconvenience, but complete loss of user control during essential interactions.

4.3.2 Focus Management and Orientation During Interaction

Focus visibility and orientation (H2) proved to be a major differentiator between the websites. On the NHS website, focus indicators were consistently visible, logically ordered, and aligned with page structure, allowing users to maintain orientation without additional effort.

The custom web application showed moderate motor impact due to inconsistent focus behaviour on the individual article page. Skipped focusable elements and faint focus indicators reduced the user's ability to track interaction state, increasing both cognitive and physical effort during navigation.

Booking.com exhibited the most severe issues in this area. Focus visibility failures on the search results and property details pages caused prolonged periods of blind tabbing, particularly within map components, filter regions, and related-property sections. These issues substantially increased navigation effort and uncertainty, reinforcing the high motor burden identified through WCAG focus-related failures.

4.3.3 Interaction Efficiency, Repetition, and Recovery Burden

Heuristic task group H3 revealed interaction inefficiencies that extend beyond technical accessibility compliance. The NHS website's simple, well-labelled layouts enabled efficient navigation without repetition, resulting in no measurable motor burden.

The custom application similarly avoided excessive repetition, although minor uncertainty arose from unexplained iconography on the article repository page. These issues did not block tasks and therefore did not materially increase motor effort.

Booking.com, however, demonstrated moderate motor impact due to interaction patterns that required repeated corrective actions. Examples included skip links that deposited users into dense filter panels, focus stalling on non-interactive elements, and unnecessary tab stops that required trial-and-error to bypass. While these patterns did not always violate WCAG success criteria, they significantly increased physical effort during sustained keyboard use.

4.3.4 Summary of Heuristic Findings

Overall, the heuristic evaluation reinforces and extends the WCAG findings by revealing how interaction complexity, focus reliability, and recovery effort shape real-world motor

accessibility. The NHS website provides a consistently low-effort interaction experience, the custom application presents isolated but impactful failures, and Booking.com exhibits systemic motor accessibility barriers driven by complex, stateful interface design.

These findings demonstrate that even when WCAG requirements are partially met, interaction patterns can still impose substantial motor burden. The heuristic evaluation therefore provides critical insight into motor accessibility outcomes that cannot be fully captured through standards-based conformance testing alone.

The following section synthesises the WCAG and heuristic findings to identify converging patterns, divergences, and the implications of these results for evaluating motor accessibility in complex web interfaces.

4.4 Synthesis of WCAG and Heuristic Evaluation Findings

The combined analysis of motor-relevant WCAG 2.2 conformance testing and heuristic evaluation reveals complementary but distinct perspectives on motor accessibility outcomes across the three evaluated websites. While both approaches frequently involved the same interaction tasks, they assessed different aspects of accessibility performance: WCAG evaluated whether keyboard-based interaction was technically achievable, whereas the heuristic evaluation examined how interaction design affected motor effort, user control, and efficiency during real-world use.

Across all three websites, areas of convergence were observed where WCAG failures aligned closely with heuristic findings. For example, keyboard traps and inaccessible interactive components identified through WCAG Success Criteria 2.1.1 (Keyboard) and 2.1.2 (No Keyboard Trap) on the individual article page of the custom web application and across multiple Booking.com pages were mirrored by high motor-impact ratings for loss of user control under heuristic task group H1 ([Appendix B](#); [Appendix C](#)). In these cases, both evaluation methods consistently indicated that core tasks could not be completed using keyboard-only input, representing direct functional barriers for users with limb loss.

However, the synthesis also highlights important divergences between WCAG conformance outcomes and heuristic motor-impact findings. Several interaction patterns that technically satisfied WCAG requirements nevertheless imposed substantial motor burden in practice. On Booking.com, for instance, WCAG testing confirmed that certain navigation elements were

keyboard accessible and that focus order was technically present. In contrast, heuristic evaluation revealed increased physical effort caused by dense focus paths, excessive tabbing through filter panels, intermittent focus stalling, and non-interactive elements receiving keyboard focus styling ([Appendix C](#), Table 8). These issues did not always correspond to WCAG failures but significantly increased interaction effort and recovery demands during sustained use.

A similar, though less severe, pattern was observed in the custom web application. While WCAG results indicated partial conformance outside of the individual article page ([Appendix B](#)), heuristic findings identified reduced focus clarity and minor orientation challenges on otherwise conformant pages ([Appendix C](#), Table 6). Although these issues did not block task completion, they introduced additional visual and physical effort that was not fully reflected in WCAG pass–fail outcomes.

In contrast, the NHS website demonstrated strong alignment between WCAG conformance and heuristic outcomes. Consistent WCAG passes across motor-relevant Success Criteria ([Appendix B](#)) corresponded with uniformly low or absent motor-impact ratings across all heuristic task groups ([Appendix C](#), Table 7). The site’s predominantly linear, informational interaction model and consistent design system resulted in both technical conformance and low-effort real-world keyboard interaction.

Taken together, these findings indicate that interaction complexity and interface statefulness are key determinants of motor accessibility outcomes. Systems with simple, predictable interaction flows were more likely to achieve both WCAG conformance and low heuristic motor impact, whereas complex, modal-driven interfaces were more prone to failures of user control, focus reliability, and interaction efficiency. While WCAG 2.2 effectively identified technical breakdowns in keyboard operability and focus handling, the heuristic evaluation revealed additional dimensions of motor burden, particularly related to effort, repetition, and recovery that are not fully captured through standards-based conformance testing alone.

Closer examination of the findings shows that motor accessibility barriers stemmed from recurring interaction design patterns rather than isolated component-level issues. These patterns included modal dialogs without keyboard-accessible dismissal mechanisms, dense vertically stacked filter panels that required prolonged sequential navigation, focus paths that included non-interactive elements, and dynamically updated interface regions with unreliable

focus recovery. Such patterns were most evident on Booking.com and, to a lesser extent, on the individual article page of the custom web application (Appendices [B](#) and [C](#)). Identifying these concrete patterns helps move beyond abstract descriptions of “interaction complexity” and provides clearer insight into how design decisions directly affect motor accessibility in practice.

This synthesis underscores the value of combining WCAG conformance testing with motor-focused heuristic evaluation to obtain a more complete picture of motor accessibility performance. By examining both technical accessibility and practical interaction experience, the evaluation provides a robust evidence base for understanding how users with limb loss may encounter accessibility barriers in real-world web use.

The results presented in Chapter 4 demonstrate how motor accessibility outcomes vary across websites when assessed through both standards-based conformance testing and heuristic usability evaluation. The following chapter draws conclusions from these findings and outlines recommendations for accessibility evaluation practice, interface design, and future standards development.

5. Conclusions and Recommendations

5.1 Conclusions

This study evaluated motor accessibility across three web platforms: the NHS website, a custom limb-loss recovery web application, and Booking.com, using a combined approach of motor-relevant WCAG 2.2 conformance testing and heuristic usability evaluation. The findings demonstrate that motor accessibility outcomes are primarily shaped by interaction complexity and interface statefulness, including the number of required interaction steps, the use of dynamic or modal interfaces, and the predictability of keyboard navigation, rather than solely by the accessibility of individual interface components.

Across the evaluated websites, systems with simple, linear, and predominantly informational interaction models, such as the NHS website, consistently achieved both high WCAG conformance and low motor-impact heuristic ratings. In contrast, complex, modal-driven and highly interactive interfaces, particularly Booking.com, exhibited systemic motor accessibility barriers despite partial compliance with individual WCAG Success Criteria. These barriers included keyboard traps, unreliable focus visibility, excessive navigation effort, and reduced user control during core tasks.

The custom limb-loss recovery application occupied a middle ground, demonstrating that even purpose-built systems can exhibit isolated but significant motor accessibility failures when interaction design choices, such as poorly managed overlays or insufficient focus handling are not carefully implemented. This highlights that motor accessibility is not guaranteed by intent alone, but is strongly influenced by execution at the interaction level.

Importantly, while WCAG 2.2 successfully identified critical technical failures (e.g. blocked keyboard interaction and focus traps), the heuristic evaluation revealed additional usability burdens such as excessive tabbing, inefficient focus paths, and unnecessary recovery actions that were not always reflected in WCAG pass–fail outcomes. These findings confirm that technical accessibility does not necessarily equate to usable accessibility for users with limb loss.

Overall, the results indicate that reliance on keyboard-only access as the sole accommodation for motor impairment is often insufficient in the context of modern, interaction-heavy web applications. A broader, more nuanced approach to motor accessibility is required, one that accounts for effort, control, and efficiency in real-world use.

5.2 Recommendations

5.2.1 Expanding Interaction Models Beyond Keyboard-Only Access

Given the demonstrated limitations of keyboard-only interaction in complex interfaces, accessibility practice should move beyond treating keyboard operability as a universal solution for motor impairment. For users with limb loss, prolonged tabbing sequences, dense focus paths, and repeated navigation actions can impose substantial physical effort even when WCAG requirements are technically met.

Designers and developers should therefore consider alternative and complementary interaction mechanisms, such as:

- configurable shortcuts and jump mechanisms
- region-based navigation controls
- reduced-focus interaction modes
- adaptive interfaces that minimise repetitive navigation

Where interaction complexity is high, providing multiple low-effort pathways to complete core tasks should be considered a baseline accessibility requirement rather than an enhancement.

5.2.2 Integrating Heuristic Evaluation into Accessibility Practice

The findings support the routine integration of motor-focused heuristic evaluation into accessibility practice alongside WCAG conformance testing. While WCAG remains essential for identifying technical accessibility failures, it does not fully account for the practical motor effort imposed by interaction design during sustained keyboard use.

Heuristic evaluation provides a complementary lens for identifying usability barriers that materially affect users with limb loss, including excessive interaction effort, loss of user control, inefficient recovery patterns, and focus behaviours that degrade usability without necessarily violating WCAG Success Criteria.

Incorporating heuristic assessment into accessibility audits would enable practitioners to move beyond binary pass–fail outcomes and to identify motor accessibility issues earlier in the design process, particularly in complex or highly interactive systems.

5.2.3 Toward Hybrid Evaluation Frameworks and Extended Standards

Beyond changes to evaluation practice, the findings point to structural limitations within current accessibility standards. WCAG 2.2 primarily evaluates whether interaction is technically possible, but offers limited guidance on acceptable levels of interaction effort, recovery burden, or sustained usability for users with motor impairments.

The results therefore suggest a need for hybrid evaluation frameworks that formally combine standards-based conformance testing with usability-based motor impact assessment. At a standards level, this may include clearer guidance on interaction-effort thresholds, stronger emphasis on focus efficiency and recovery, and extensions or supplements to WCAG that explicitly address motor accessibility in complex, stateful interfaces.

For users with limb loss in particular, future accessibility standards should move beyond binary notions of accessibility and more directly address whether interaction remains feasible, efficient, and controllable over time.

5.2.4 Implications for Designers and Accessibility Auditors

For practitioners, the findings highlight that achieving WCAG conformance should be treated as a minimum requirement rather than an endpoint. Designers should critically evaluate how interaction patterns scale under keyboard-only use and how users maintain control across dynamic interface states.

Accessibility auditors are encouraged to adopt task-based, motor-focused evaluation approaches, ensuring that assessments reflect realistic usage scenarios rather than isolated component checks.

5.2.5 Future Research Involving Users with Limb Loss

Future research should extend this work through direct user involvement, particularly with individuals with limb loss at different stages of recovery. Task-based usability testing with real users could help validate heuristic motor-impact ratings and provide empirical insight into interaction fatigue, effort accumulation, and long-term usability. Combining expert evaluation with user-centred methods would enable a more comprehensive understanding of how motor accessibility barriers manifest in real-world use and how design interventions can be prioritised more effectively.

5.3 Final Remarks

This study demonstrates that meaningful motor accessibility cannot be assessed through technical conformance alone. By combining WCAG 2.2 evaluation with motor-focused heuristic analysis, it becomes possible to identify both overt accessibility failures and subtler interaction burdens that significantly affect users with limb loss.

As web interfaces continue to increase in complexity, accessibility practice must evolve accordingly. A shift toward hybrid evaluation methods, expanded interaction models, and motor-aware design principles is essential to ensure that accessibility standards remain effective in real-world contexts.

6. Reflection

This project provided an opportunity to critically reflect on how motor accessibility is assessed in practice and how different evaluation methods shape the understanding of accessibility outcomes for users with limb loss. While I initially approached WCAG conformance testing and heuristic evaluation as clearly distinct activities, applying both methods through a motor-impairment lens revealed a more complex relationship between technical compliance and real-world usability than I had anticipated.

One of the most significant reflections from this work concerns the overlap between WCAG evaluation and heuristic usability assessment when WCAG is applied with a specific focus on motor accessibility. Because the WCAG Success Criteria selected for this study were explicitly motor-relevant, many of the same keyboard-based tasks were necessarily performed during both evaluations. This initially created uncertainty about where WCAG evaluation ended and heuristic evaluation began. Over time, however, this overlap became one of the most valuable insights of the study. It made clear that although WCAG and heuristic evaluation may involve similar interaction tasks, they answer fundamentally different questions. WCAG evaluation allowed me to determine whether keyboard interaction was technically possible, whereas heuristic evaluation required me to consider how much effort, control, and sustained interaction that keyboard use actually demanded in practice.

Looking back at the original aim of this project, I believe it was largely achieved. By evaluating WCAG 2.2 through a motor-impairment lens and applying heuristic analysis alongside it, I was able to assess not only whether standards technically support users with limb loss, but whether they do so in practice. The findings demonstrated that while WCAG captures critical failures, it does not fully account for sustained interaction effort, reinforcing the need for complementary evaluation approaches when assessing motor accessibility in practice.

This distinction became particularly clear when evaluating complex, stateful interfaces such as Booking.com. WCAG testing identified clear failures, including keyboard traps and inconsistent focus visibility, which already indicated serious accessibility barriers. However, the heuristic evaluation revealed additional layers of motor burden that were not always captured by WCAG outcomes alone. For example, although some navigation paths technically passed WCAG checks, the practical experience of tabbing through dense filter panels,

repeatedly encountering non-interactive focus stops, and recovering from stalled focus behaviour significantly increased physical effort during sustained use. This reinforced the idea that WCAG compliance alone should not be treated as a definitive indicator of accessibility quality, particularly for users with motor impairments.

Although ARIA was reviewed during the literature phase of this project, it was not directly assessed as part of the empirical evaluation, which focused on motor-relevant WCAG 2.2 Success Criteria. However, evaluating ARIA-heavy interfaces, particularly Booking.com, made its influence on motor accessibility impossible to ignore. Issues related to keyboard traps, focus loss, and modal behaviour were closely tied to complex ARIA-driven interaction patterns. This reinforced for me that while ARIA can enhance accessibility when implemented carefully, poor or overly complex ARIA usage can significantly exacerbate motor accessibility barriers, particularly for users relying on sustained keyboard interaction.

Reflecting on this process also made the subjective nature of heuristic evaluation more apparent. Unlike WCAG, which provides clearly defined Success Criteria and pass-fail outcomes, heuristic assessment requires judgement about what constitutes meaningful motor effort, loss of control, or inefficient interaction. I became more aware of the importance of being transparent and systematic when documenting heuristic findings, particularly when interpreting borderline cases where interactions were technically possible but practically burdensome. Comparing heuristic findings directly with WCAG results helped me ground these judgements and avoid overstating usability issues that did not meaningfully affect task completion.

This process also made me more aware of my own role as the evaluator and the potential for researcher bias within heuristic assessment. As the sole evaluator, my interpretation of what constituted “meaningful” motor effort or loss of control was inevitably shaped by my understanding of limb-loss-related interaction challenges and by the study’s motor-focused framing. While grounding heuristic findings against WCAG results helped mitigate this bias, it remains an inherent limitation of expert-led usability evaluation.

Another important reflection concerns interaction complexity as a driver of motor accessibility outcomes. Through comparing the NHS website, the custom web application, and Booking.com, it became increasingly clear to me that interaction complexity and interface statefulness played a central role in determining accessibility performance. The NHS website,

with its largely linear, informational structure and consistent design system, performed well across both WCAG and heuristic evaluation. In contrast, interfaces that relied heavily on modals, dense interactive regions, and dynamic interface states were more prone to both technical failures and increased motor burden. This comparison helped me better understand how accessibility issues emerge not only from missing features, but from the cumulative demands placed on users during extended interaction.

A further limitation of this study is the absence of direct user testing with individuals with limb loss. While the task-based evaluation approach was appropriate for comparing WCAG and heuristic methods, the findings are based on expert analysis rather than lived user experience. Reflecting on the results, particularly those relating to sustained interaction effort and fatigue, it is clear that involving users directly could have provided deeper insight into how these burdens are experienced over time and across different stages of recovery.

Conducting both evaluation methods also changed how I think about accessibility evaluation more broadly. Prior to this project, I viewed WCAG primarily as a sufficient benchmark for accessibility assessment. While I still recognise its importance, this study highlighted its limitations when applied in isolation, particularly for motor accessibility. The heuristic evaluation provided insights into interaction effort, recovery patterns, and sustained usability that WCAG alone could not fully capture. This has influenced how I would approach accessibility evaluation in future work, encouraging a more holistic approach that combines standards-based compliance with usability-focused analysis.

Overall, this project deepened my understanding of motor accessibility as a practical, lived interaction experience rather than a purely technical requirement. It reinforced the importance of evaluating not just whether users *can* interact with a system, but whether they can do so efficiently, predictably, and without excessive physical effort. The reflective process itself was a valuable learning experience, allowing me to critically assess my assumptions, refine my evaluation approach, and develop a more nuanced perspective on accessibility for users with limb loss.

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9. Appendices

Appendix A: Motor Impairment-Relevant WCAG 2.2 Success Criteria

Table 2 – Summary of WCAG 2.2 Success Criteria Relevant to Motor Impairment

Principle	Guideline	Success Criteria	Level	Brief Description	Relevance to Limb Loss / Motor Impairment
Operable	2.1 Keyboard Accessible	2.1.1 Keyboard	A	All functionality must be available by keyboard.	Many limb-loss users rely on keyboard-only navigation or alternative input devices.
Operable	2.1 Keyboard Accessible	2.1.2 No Keyboard Trap	A	Users should never get trapped in an element when using a keyboard.	Prevents navigation barriers for one-handed or adaptive keyboard users.
Operable	2.1 Keyboard Accessible	2.1.4 Character Key Shortcuts	A	Single-key shortcuts must be removable, remappable, or disabled.	Prevents accidental activation due to imprecise one-handed input.
Operable	2.2 Enough Time	2.2.1 Timing Adjustable	A	Users must be able to extend or turn off time limits.	Users with motor impairments may take longer to complete tasks.
Operable	2.2 Enough Time	2.2.2 Pause, Stop, Hide	A	Auto-updating/moving content must be controllable.	Reduces pressure and interruptions for slow or one-handed input.
Operable	2.4 Navigable	2.4.1 Bypass Blocks	A	Provides a way to skip repeated content.	Reduces repetitive input effort for one-handed navigation.
Operable	2.4 Navigable	2.4.2 Page Titled	A	Pages must have descriptive titles.	Helps users locate content faster, reducing unnecessary interaction.
Operable	2.4 Navigable	2.4.3 Focus Order	A	Focus must move in a logical and predictable order.	Ensures smooth keyboard navigation for users with reduced precision.
Operable	2.4 Navigable	2.4.4 Link Purpose (In Context)	A	Links must be clearly described.	Prevents wasted effort clicking ambiguous targets.
Operable	2.4 Navigable	2.4.5 Multiple Ways	AA	Provide more than one way to locate content.	Reduces navigation workload for users with limited dexterity.
Operable	2.4 Navigable	2.4.6 Headings and Labels	AA	Headings/labels must be descriptive.	Improves scanning efficiency; reduces unnecessary movement.

Operable	2.4 Navigable	2.4.7 Focus Visible	AA	Keyboard focus must always be visible.	Essential for tracking navigation using one hand or switch controls.
Operable	2.4 Navigable	2.4.11 Focus Not Obscured	AA	Focus indicators must not be hidden behind other content.	Prevents users from losing track of focus location while navigating.
Operable	2.5 Input Modalities	2.5.1 Pointer Gestures	A	Complex gestures must have simple alternatives.	Multi-finger/swipe gestures can be difficult or impossible one-handed.
Operable	2.5 Input Modalities	2.5.2 Pointer Cancellation	A	Clicking must allow cancellation before completion.	Helps reduce errors from unsteady or imprecise pointer movement.
Operable	2.5 Input Modalities	2.5.3 Label in Name	A	Visible labels must match the programmatic name.	Supports speech-input users, common in motor impairment.
Operable	2.5 Input Modalities	2.5.7 Dragging Movements	AA	Drag-and-drop must have alternatives.	Dragging is one of the hardest actions for users with limb loss.
Operable	2.5 Input Modalities	2.5.8 Target Size (Minimum)	AA	Pointer targets must be sufficiently large.	Large targets reduce precision demands for one-handed use.
Understandable	3.2 Predictable	3.2.1 On Focus	A	Elements must not trigger unexpected changes on focus.	Prevents unintentional actions from keyboard-only navigation.
Understandable	3.2 Predictable	3.2.2 On Input	A	Changing input should not trigger unexpected actions.	Helps avoid accidental submissions caused by imprecise motor control.
Understandable	3.2 Predictable	3.2.3 Consistent Navigation	AA	Navigation mechanisms must appear in the same order.	Supports predictable and efficient interaction.
Understandable	3.2 Predictable	3.2.4 Consistent Identification	AA	Components must be identified consistently.	Reduces cognitive + motor effort required to learn interactions.
Understandable	3.2 Predictable	3.2.6 Consistent Help	A	Help must appear consistently where offered.	Reduces search effort for instructional support.
Understandable	3.3 Input Assistance	3.3.1 Error Identification	A	Errors must be clearly identified.	Helps users recover from motor-related mistakes.
Understandable	3.3 Input Assistance	3.3.2 Labels or Instructions	A	Input must include clear instructions.	Minimises unnecessary repeated actions.
Understandable	3.3 Input Assistance	3.3.3 Error Suggestion	AA	Suggestions must be provided when errors occur.	Helps compensate for input inaccuracies common with limb loss.

Understandable	3.3 Input Assistance	3.3.4 Error Prevention (Legal/Financial/Data)	AA	Critical actions must be reversible or confirmed.	Prevents serious mistakes caused by imprecise one-handed actions.
Understandable	3.3 Input Assistance	3.3.7 Redundant Entry	A	Users must not need to re-enter the same information.	Reduces physical effort for users with slower/more difficult input.
Understandable	3.3 Input Assistance	3.3.8 Accessible Authentication (Minimum)	AA	Authentication must not rely on difficult input-based tasks.	Tasks like handwriting, dragging, or precision clicking are difficult with limb loss.

Appendix B: WCAG 2.2 Accessibility Evaluation Findings

This appendix presents WCAG 2.2 accessibility evaluation findings for all sampled websites, conducted using the WCAG-EM methodology. The evaluations targeted WCAG 2.2 Level A and AA Success Criteria, with a specific focus on motor accessibility relevant to users with limb loss.

Across all websites, testing combined automated accessibility scanning to establish a baseline with detailed manual keyboard-only evaluation to assess operability, focus management, interaction effort, and task completion. Evaluations were conducted using Google Chrome (latest version) on macOS, using keyboard-only navigation to reflect motor-impaired interaction scenarios.

All Success Criteria listed in Appendix A were assessed across the sampled pages and recorded in the WCAG-EM report tool with outcomes of *Pass*, *Fail*, *Not present*, or *Cannot tell*, as appropriate.

To maintain clarity and conciseness, this appendix highlights motor-relevant Success Criteria that produced substantive evaluation outcomes across the sample, primarily Pass and Fail results. Success Criteria recorded as *Not present*, *Not checked*, or *Cannot tell* are documented in the archived WCAG-EM HTML report but are not reproduced in full here.

Automated findings not directly related to motor accessibility (e.g. semantic structure or screen-reader-specific issues) were recorded for completeness but were not prioritised for manual verification in accordance with the motor-impairment focus of the study.

Full WCAG-EM HTML reports were generated for this evaluation and archived as supporting documentation. The full WCAG-EM HTML reports for each evaluated website are provided as supplementary material accompanying this submission.

Appendix B.1: WCAG 2.2 Accessibility Evaluation Findings: Custom Limb-Loss Recovery Web Application

B.1.1 Evaluation Overview

A representative sample of three public-facing pages was evaluated:

- Home page
- Article repository page
- Individual article page

These pages collectively represent the core interaction model of the application, including navigation, content discovery, and engagement with interactive components.

In accordance with WCAG-EM reporting conventions, outcomes were recorded against the full WCAG 2.2 AA Success Criteria set. For this evaluation, the WCAG-EM tool recorded the following coverage:

- Reported on: 29 of 55 WCAG 2.2 AA Success Criteria
- Passed: 13
- Failed: 4
- Cannot tell: 2
- Not present: 10
- Not checked: 26

These figures reflect the scoped audit design and motor-accessibility focus of this study (Appendix A). Success Criteria outside the defined motor-impairment scope, or not applicable to the sampled pages and interaction tasks, were documented in the WCAG-EM tool as *Not checked*, *Not present*, or *Cannot tell*, in line with WCAG-EM guidance. All Success Criteria defined in Appendix A were assessed across the selected sample.

B.1.2 Summary of Accessibility Outcomes

Overall, the Custom Limb-Loss Recovery Web Application demonstrates partial conformance with WCAG 2.2 Success Criteria relevant to motor accessibility.

- The home page and article repository page generally support keyboard-only interaction, logical focus order, visible focus indicators, and adequately sized interactive targets.
- The individual article page presents significant motor accessibility barriers, including inaccessible interactive components, inconsistent focus order, reduced focus visibility, and the absence of a mechanism to bypass repeated content.

These failures require additional keyboard navigation actions and, in some cases, prevent task completion using keyboard-only input.

B.1.3 Motor-Relevant WCAG 2.2 Findings

Table 3 summarises the WCAG 2.2 Level A and AA Success Criteria relevant to motor accessibility, as defined in Appendix A, and their evaluation outcomes.

Table 3 - WCAG 2.2 Motor Accessibility Findings (Custom Web Application)

WCAG SC	Success Criterion	Level	Result	Affected Pages	Motor Accessibility Impact
2.1.1	Keyboard	A	Fail	Individual article page	Multiple interactive components are not reachable or operable using keyboard-only input, preventing task completion.
2.1.2	No Keyboard Trap	A	Pass	All pages	Keyboard focus can move freely into and away from interactive elements without trapping.
2.4.1	Bypass Blocks	A	Fail	All pages	No mechanism is provided to bypass repeated navigation content, increasing physical navigation effort.

2.4.2	Page Titled	A	Pass	All pages	Pages have clear and descriptive titles, supporting orientation.
2.4.3	Focus Order	A	Fail	Individual article page	Keyboard focus skips interactive sections and does not follow the visual or logical reading order.
2.4.4	Link Purpose (In Context)	A	Pass	All pages	Link purpose is clear from visible text or surrounding context.
2.4.6	Headings and Labels	AA	Pass	All pages	Headings and labels are descriptive and support efficient navigation.
2.4.7	Focus Visible	AA	Fail	Individual article page	Focus indicators become difficult to perceive in certain components, reducing focus trackability.
2.4.11	Focus Not Obscured (Minimum)	AA	Pass	All pages	Focus indicators are not hidden or obscured by other content.
2.5.3	Label in Name	A	Pass	All pages	Visible labels match programmatic names, supporting predictable keyboard use.
2.5.8	Target Size (Minimum)	AA	Pass	All pages	Interactive targets meet minimum size requirements, reducing fine motor precision demands.
3.2.1	On Focus	A	Pass	All pages	No unexpected changes in context occur when elements receive focus.

3.2.2	On Input	A	Pass	All pages	User input does not trigger unexpected changes in context.
3.2.3	Consistent Navigation	AA	Pass	All pages	Navigation mechanisms are presented consistently across pages.
3.3.2	Labels or Instructions	A	Pass	All pages	Clear labels and instructions are provided wherever user input is required.
3.3.7	Redundant Entry	A	Pass	All pages	Users are not required to re-enter the same information across pages.

Appendix B.2: WCAG 2.2 Accessibility Evaluation Findings: NHS Website

B.2.1 Evaluation Overview

A representative sample of three public-facing pages was evaluated:

- Home page
- Health A–Z Index
- Amputation Information page

These pages represent core navigation pathways, content discovery mechanisms, and informational interactions commonly used by the public, and therefore constitute an appropriate sample for evaluating motor-accessibility conformance.

In accordance with WCAG-EM reporting conventions, outcomes were recorded against the full WCAG 2.2 AA Success Criteria set. For this evaluation, the WCAG-EM tool recorded the following coverage:

- **Reported on:** 29 of 55 WCAG 2.2 AA Success Criteria
- **Passed:** 13
- **Failed:** 0
- **Cannot tell:** 1
- **Not present:** 15

- **Not checked: 26**

These figures reflect the scoped audit design and motor-accessibility focus of this study (Appendix A). Success Criteria outside the defined motor-impairment scope, or not applicable to the sampled pages and interaction tasks, were recorded in the WCAG-EM tool as *Not checked*, *Not present*, or *Cannot tell*, in line with WCAG-EM guidance. All Success Criteria defined in Appendix A were assessed across the selected sample.

B.2.2 Summary of Accessibility Outcomes

Across the evaluated sample, the NHS website demonstrates a high level of conformance with WCAG 2.2 Success Criteria relevant to motor accessibility.

All sampled pages support reliable keyboard-only navigation, logical and predictable focus order, clearly visible focus indicators, descriptive links and headings, and consistently implemented skip links that allow users to bypass repeated navigation content. No keyboard traps, inaccessible interactive components, or focus-management issues were identified during manual evaluation.

The evaluated pages are primarily informational in nature and involve limited interaction complexity. This design characteristic aligns with WCAG 2.2 requirements by minimising interaction complexity, limiting the number of required focusable elements, and providing consistent bypass mechanisms, thereby reducing the likelihood of excessive keyboard navigation for motor-impaired users. No significant motor-accessibility barriers were identified within the evaluated sample.

B.2.3 Motor-Relevant WCAG 2.2 Findings

Table 4 summarises the WCAG 2.2 Level A and AA Success Criteria relevant to motor accessibility, as defined in Appendix A, and their evaluation outcomes for the NHS website sample.

Table 4 - WCAG 2.2 Motor Accessibility Findings (NHS Website)

WCAG SC	Success Criterion	Level	Result	Affected Pages	Motor Accessibility Impact
2.1.1	Keyboard	A	Pass	All pages	All navigation and interactive elements are operable using keyboard-only input.
2.1.2	No Keyboard Trap	A	Not present	All pages	No components introduce conditions where keyboard focus could become trapped.
2.4.1	Bypass Blocks	A	Pass	All pages	Skip links are consistently provided, reducing repetitive navigation effort.
2.4.2	Page Titled	A	Pass	All pages	Pages have clear and descriptive titles supporting orientation.
2.4.3	Focus Order	A	Pass	All pages	Focus follows a logical and predictable sequence.
2.4.4	Link Purpose (In Context)	A	Pass	All pages	Link purpose is clear from visible text or surrounding context.
2.4.6	Headings and Labels	AA	Pass	All pages	Headings and labels support efficient scanning and navigation.
2.4.7	Focus Visible	AA	Pass	All pages	Focus indicators are clearly visible on all interactive elements.

2.4.11	Focus Not Obscured (Minimum)	AA	Pass	All pages	Focus indicators are not hidden or obscured by other content.
2.5.3	Label in Name	A	Pass	All pages	Visible labels match programmatic names, supporting predictable interaction.
3.2.1	On Focus	A	Pass	All pages	No unexpected changes in context occur on focus.
3.2.2	On Input	A	Pass	All pages	User input does not trigger unexpected context changes.
3.2.3	Consistent Navigation	AA	Pass	All pages	Navigation mechanisms are consistent across pages.

Appendix B.3: WCAG 2.2 Accessibility Evaluation Findings: Booking.com

B.3.1 Evaluation Overview

A representative sample of three public-facing pages was evaluated:

- Home page (search interface)
- Search results page
- Property details page

These pages represent the primary user journey for discovering, evaluating, and saving accommodation, including search, filtering, navigation, and interaction with modal components. As such, they form a representative sample of Booking.com's core task flows for motor-accessibility evaluation.

In accordance with WCAG-EM reporting conventions, outcomes were recorded against the full WCAG 2.2 AA Success Criteria set. For this evaluation, the WCAG-EM tool recorded the following coverage:

- **Reported on:** 29 of 55 WCAG 2.2 AA Success Criteria

- **Passed:** 13
- **Failed:** 3
- **Cannot tell:** 3
- **Not present:** 10
- **Not checked:** 26

These figures reflect the scoped audit design and motor-accessibility focus of this study (Appendix A). Success Criteria outside the defined motor-impairment scope, or not applicable to the sampled pages and interaction tasks, were documented in the WCAG-EM tool as *Not checked*, *Not present*, or *Cannot tell*, in line with WCAG-EM guidance. All Success Criteria defined in Appendix A were assessed across the selected sample.

B.3.2 Summary of Accessibility Outcomes

Overall, Booking.com demonstrates partial conformance with WCAG 2.2 Success Criteria relevant to motor accessibility across the evaluated sample.

Although many foundational requirements, such as page titles, bypass mechanisms, descriptive links and headings, and minimum target sizes, were met, multiple critical interaction failures were consistently observed during manual testing. Across all sampled pages, keyboard traps within modal dialogs prevent users from exiting or completing key tasks using keyboard-only input. Focus visibility is also inconsistent on the search results and property details pages, resulting in blind tabbing and increased navigation effort.

In summary, the presence of keyboard traps, unreliable focus visibility, and blocked task completion represents significant motor-accessibility barriers for users who rely on keyboard or alternative input methods.

B.3.3 Motor-Relevant WCAG 2.2 Findings

Table 5 summarises the WCAG 2.2 Level A and AA Success Criteria relevant to motor accessibility, as defined in Appendix A, and their evaluation outcomes for the Booking.com sample.

Table 5 - WCAG 2.2 Motor Accessibility Findings (Booking.com)

WCAG SC	Success Criterion	Level	Result	Affected Pages	Motor Accessibility Impact
2.1.1	Keyboard	A	Fail	All pages	Core tasks cannot be reliably completed using keyboard-only input due to modal-related focus and interaction failures.
2.1.2	No Keyboard Trap	A	Fail	All pages	Keyboard focus becomes trapped within the “Save” modal with no keyboard-accessible method to exit or dismiss it.
2.4.1	Bypass Blocks	A	Pass	All pages	A bypass mechanism is provided, reducing repetitive navigation effort.
2.4.2	Page Titled	A	Pass	All pages	Pages have descriptive titles supporting orientation.
2.4.3	Focus Order	A	Pass	All pages	Focus generally follows a logical sequence, though

					overall task completion is undermined by modal and focus failures.
2.4.4	Link Purpose (In Context)	A	Pass	All pages	Link purpose is clear from visible text or context, reducing unnecessary interaction.
2.4.6	Headings and Labels	AA	Pass	All pages	Headings and labels support efficient scanning and navigation.
2.4.7	Focus Visible	AA	Fail	Search results; Property details	Focus indicator becomes lost or difficult to perceive in key areas, resulting in blind tabbing and loss of orientation.
2.4.11	Focus Not Obscured (Minimum)	AA	Pass	All pages	When visible, focus indicators are not obscured by other content.
2.5.3	Label in Name	A	Pass	All pages	Visible labels match accessible names, supporting predictable control activation.
2.5.8	Target Size (Minimum)	AA	Pass	All pages	Interactive targets are sufficiently large to reduce fine motor precision demands.

3.2.1	On Focus	A	Pass	All pages	No unexpected context changes occur on focus.
3.2.2	On Input	A	Pass	All pages	Input changes do not trigger unexpected context changes.
3.2.3	Consistent Navigation	AA	Cannot tell	All pages	The audit did not provide sufficient evidence to confirm navigation consistency across contexts at the sample level.
3.3.2	Labels or Instructions	A	Pass	All pages	Labels and instructions are provided where user input is required.
3.3.7	Redundant Entry	A	Pass	All pages	Users are not required to re-enter previously supplied information.

Appendix C - Heuristic Evaluation Findings

This appendix presents the heuristic evaluation findings for the three evaluated websites: the Custom Limb-Loss Recovery Web Application, the NHS website (nhs.uk), and Booking.com. The heuristic evaluation complements the WCAG 2.2 assessment by examining motor accessibility in terms of interaction effort, control, and usability during keyboard-only use.

Each website was evaluated using six motor-relevant heuristic task groups (H1–H6), applied consistently across a representative sample of pages. Page-level observations were recorded during keyboard-based interaction and subsequently synthesised to produce a consolidated motor impact rating (None, Low, Moderate, or High) for each heuristic at the website level.

Motor impact ratings reflect the degree to which interaction design increased physical effort, reduced user control, or impeded task completion for users with motor impairments. Detailed page-level observations underpinning these ratings are presented within the tables that follow, while cross-site comparison and interpretation are addressed in the Results section.

C.1: Heuristic Evaluation Summary – Custom Limb-Loss Recovery Web Application

Table 6 - Motor-Focused Heuristic Evaluation Summary – Custom Limb-Loss Recovery Web Application

Task Group	Motor Category	Heuristic(s) Assessed	Overall Observation (Synthesised Across Pages)	Website-Level Motor Impact
H1	Keyboard & alternative input operability	#3 User Control & Freedom; #7 Flexibility & Efficiency of Use	While the home and article repository pages support reliable keyboard-only interaction without loss of control, the individual article page exhibits a critical keyboard trap when activating the “Share” control. Focus becomes trapped within a tooltip-style menu with no keyboard-accessible method to exit or dismiss it. Additional interactive elements are skipped during tab navigation, preventing consistent keyboard access.	High – loss of control and blocked task completion

H2	Focus visibility & orientation	#1 Visibility of System Status	Focus visibility is sufficient on the home and repository pages, though reduced contrast occasionally requires increased visual attention. On the individual article page, focus is inconsistently applied, skipped on some elements, and visually faint when present. This results in reduced orientation and increased effort to determine interaction state.	Moderate – reduced orientation and increased effort
H3	Interaction effort & repetition	#6 Recognition Rather Than Recall; #7 Flexibility & Efficiency of Use	Across the site, content structure and labelling generally support recognition rather than recall, and no excessive repetition or repeated navigation patterns were observed. Minor uncertainty exists on the repository page due to unexplained non-interactive iconography, but this does not impede task completion.	None – no meaningful increase in motor effort

H4	Error tolerance & recovery effort	#5 Error Prevention; #9 Help Users Recognize, Diagnose, and Recover from Errors	Error scenarios across the site are limited and handled with low-effort recovery. Where invalid input occurs, feedback is clear and recovery actions are immediate and keyboard-accessible. On the article page, unintended input can be easily reversed without repetition or loss of control.	None – effective recovery with minimal effort
H5	Target size & precision demand	#5 Error Prevention; #7 Flexibility & Efficiency of Use	Interactive targets across all pages are sufficiently sized, well spaced, and fully operable via keyboard. No interactions require precise targeting, dense navigation, or fine motor control.	None – no precision-related motor burden
H6	Consistency & predictability	#4 Consistency & Standards; #6 Recognition Rather Than Recall	Layout, navigation patterns, and interaction behaviours are consistent across pages. Controls behave predictably and align with established interface conventions, reducing learning effort	None – predictable and stable interaction patterns

			and exploratory interaction.	
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C.2: Heuristic Evaluation Summary – NHS Website (nhs.uk)

Table 7 - Motor-Focused Heuristic Evaluation Summary – NHS Website (nhs.uk)

Task Group	Motor Category	Heuristic(s) Assessed	Overall Observation (Synthesised Across Pages)	Website-Level Motor Impact
H1	Keyboard & alternative input operability	#3 User Control & Freedom; #7 Flexibility & Efficiency of Use	Across all evaluated pages (Home, Health A–Z, and Amputation Information), all navigation elements, links, and controls are fully operable using keyboard-only input. Skip-to-content links, breadcrumbs, and logical focus order consistently support efficient movement and user control. No keyboard traps or blocked interactions were identified.	None – full keyboard operability with strong user control
H2	Focus visibility & orientation	#1 Visibility of System Status	Keyboard focus remains consistently visible across all pages and	None – clear focus visibility and orientation

			interactive elements. Focus indicators are clear and sufficiently contrasted, allowing users to reliably track position and maintain orientation during navigation. Focus order follows the visual and semantic structure of each page.	
H3	Interaction effort & repetition	#6 Recognition Rather Than Recall; #7 Flexibility & Efficiency of Use	Page layouts are simple, well labelled, and logically structured. Users can recognise available options without relying on memory, and navigation does not require excessive tabbing or repeated actions. Informational pages are largely linear, further reducing interaction effort.	None – efficient interaction with minimal effort
H4	Error tolerance & recovery effort	#5 Error Prevention; #9 Help Users Recognise, Diagnose, and Recover from Errors	Where error states are possible (e.g. search with no results), the system provides clear feedback and multiple, keyboard-accessible recovery paths. On content-heavy	None – low-effort recovery and strong error tolerance

			pages with no complex inputs, navigation errors are easily recoverable using standard mechanisms such as breadcrumbs or header navigation.	
H5	Target size & precision demand	#5 Error Prevention; #7 Flexibility & Efficiency of Use	Interactive elements across all evaluated pages are sufficiently large, well spaced, and easy to activate using keyboard navigation. No interactions require precise targeting or fine motor control.	None – no precision-related motor burden
H6	Consistency & predictability	#4 Consistency & Standards; #6 Recognition Rather Than Recall	Layout, navigation patterns, and interaction behaviour are consistent across pages and aligned with the NHS design system. Users can accurately predict where elements are located and how they will behave, reducing learning effort and unnecessary interaction.	

C.3: Heuristic Evaluation Summary – Booking.com

Table 8 - Motor-Focused Heuristic Evaluation Summary – Booking.com

Task Group	Motor Category	Heuristic(s) Assessed	Overall Observation (Synthesised Across Pages)	Website-Level Motor Impact
H1	Keyboard & alternative input operability	#3 User Control & Freedom; #7 Flexibility & Efficiency of Use	Across all evaluated pages (Home, Search Results, Property Details), activating the “Save” control opens a modal dialog that traps keyboard focus. Users cannot dismiss, escape, or return to the previous context using keyboard- only input. This behaviour repeatedly blocks a core task (saving/unsaving a property) and results in loss of control and forced abandonment.	High – critical task blocked and persistent loss of user control
H2	Focus visibility & orientation	#1 Visibility of System Status	Focus visibility is inconsistent across the site. While focus remains visible on the home page, it becomes visually lost on the search results page (“Things to do”	High – loss of orientation and significantly increased navigation effort

			section) and on the property details page (map component and related property lists). These failures force blind tabbing and prevent users from reliably tracking their current position.	
H3	Interaction effort & repetition	#6 Recognition Rather Than Recall; #7 Flexibility & Efficiency of Use	Labels and controls generally support recognition rather than recall; however, several interaction patterns increase effort. These include excessive tabbing caused by skip links landing in dense filter panels, focus intermittently stalling on star-rating elements, and non-interactive elements receiving keyboard focus styling. These issues introduce unnecessary repetition and recovery actions.	Moderate – increased physical effort and inefficient navigation
H4	Error tolerance & recovery effort	#5 Error Prevention; #9 Help Users Recognize,	Error-prone interactions are largely prevented through constrained inputs and intelligent	Low – effective error prevention and minimal recovery burden

		Diagnose, and Recover from Errors	interpretation of ambiguous data (e.g. locations, guest counts). Core tasks rarely trigger blocking error states, and recovery does not require repeated input or complex corrective actions.	
H5	Target size & precision demand	#5 Error Prevention; #7 Flexibility & Efficiency of Use	Interactive elements across all pages are sufficiently large, well spaced, and keyboard reachable. No interactions require fine motor precision or tightly constrained focus placement.	Low – no precision-related motor burden
H6	Consistency & predictability	#4 Consistency & Standards; #6 Recognition Rather Than Recall	Layout, navigation structure, and interaction patterns are largely consistent across pages. Repeated components (property cards, filters, icons) behave predictably, and non-standard icons are generally supported by labels or tooltips.	Low – predictable interaction despite other accessibility failures