Methodological Standards in Accessibility Research on Motor Impairments: A Survey

ZHANNA SARSENBAYEVA, The University of Melbourne, Australia
NIELS VAN BERKEL, Aalborg University, Denmark
EDUARDO VELLOSO, JORGE GONCALVES, and VASSILIS KOSTAKOS, The University of Melbourne, Australia

The design and evaluation of accessibility technology is a core component of the computer science landscape, aiming to ensure that digital innovations are accessible to all. One of the most prominent and long-lasting areas of accessibility research focuses on motor impairments—deficiencies that affect the ability to move, manipulate objects, and interact with the physical world. In this survey article, we present an extensive overview of the past two decades of research into accessibility for people with motor impairments. Following a structured selection process, we analyzed the study details as reported in 177 relevant papers. Based on this analysis, we critically assess user representation, measurement instruments, and existing barriers that exist in accessibility research. Finally, we discuss future directions for accessibility research within the computer science domain.

CCS Concepts: • **Human-centered computing → Empirical studies in accessibility;**

Additional Key Words and Phrases: Accessibility, motor impairments, motor-impaired users, methodology

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1 INTRODUCTION

Clicking, pointing, and dragging are fundamental to interacting with computers, and most of us take them for granted. Yet according to the World Health Organization, 15% of the world's population has been diagnosed with motor impairments [172], which makes it challenging to interact with technology. For example, in the United States, this number is estimated to be 39 million [4]. Often, these impairments are a result of spinal cord injuries, degenerative nerve and muscle diseases, stroke, or missing upper limbs [223]. Through a survey of 20 years of accessibility research,

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Authors' addresses: Z. Sarsenbayeva, E. Velloso, J. Goncalves, and V. Kostakos, The University of Melbourne, Parkville, Victoria, 3010, Australia; emails: {zhanna.sarsenbayeva, eduardo.velloso, jorge.goncalves, vassilis.kostakos}@unimelb.edu.au; N. van Berkel, Aalborg University, Fredrik Bajers Vej 7K, 9220, Aalborg, East Denmark; email: nielsvanberkel@cs.aau.dk.

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ranging from 2000 to 2020, we summarize the research methodologies that have been developed to study motor-impaired users—that is, those with deficiencies that affect their ability to move, manipulate objects, and interact with the physical world. Our survey provides a much-needed overview of methodological concerns and standards that exist in accessibility research in studies with users with motor impairments. Concretely, our article provides a systematic review of methodological approaches to conduct accessibility research for motor impairments. To the best of our knowledge, this is the first work to focus on methodological aspects researching motor impairments, whereas existing surveys on motor impairments focus on technological solutions designed to assist people with motor impairments [192, 226].

By following robust methodological standards, the accessibility research community can ensure that the generated outcomes will subsequently lead to the design and creation of high-quality technological solutions that address the needs of motor-impaired users. Effectively addressing the needs of permanently impaired users in designing technology is crucial for several reasons. Abascal and Nicolle [6] state that people with permanent impairments are more likely to have a higher dependence on computers, because digital tools offer vital support in personal and professional communication, control over their environment, assisted mobility, and access to services. As a result, digital exclusion for permanently impaired users can lead to a restricted socially active and independent lifestyle [6]. Furthermore, there exist untapped financial incentives, as people with disabilities control a large amount of annual discretionary income (e.g., $220 billion in the United States alone) [191]. Moreover, due to the growth of our aging populations, particularly in the Western world [3], "enabling accessible technology is a growth opportunity" [30]. Finally, designing for inclusion is supported by many legal acts. This includes, but is not limited to, Section 508 of the Rehabilitation Act of 1973 and Americans with Disabilities Act (ADA) in the United States and the European Accessibility Act in Europe.

Our results show a recent shift in focus from desktop computers toward smartphones and wearables in devices used in studies with motor-impaired participants. Our results also show that there is a significant difference in device prevalence depending on the type of the study, with eye-trackers being more common for the laboratory studies, whereas other equipment is more prevalent in field studies. Our results further identify common tasks and measure variables used to quantify the user's functional capabilities in accessibility research in motor impairments. Furthermore, our findings highlight that the average sample size is significantly greater in studies conducted with participants from a mixed participant group that includes both able-bodied and motor-impaired participants as compared to the studies conducted strictly with motor-impaired participants. We further demonstrate that laboratory studies are more likely to recruit able-bodied participants, whereas field studies have a higher chance to involve motor-impaired participants. Finally, we discuss opportunities for new research directions for the field of accessibility when developing solutions for motor-impaired users, such as the creation of novel modeling techniques to avoid longitudinal experiments, or accounting for the user's individual characteristics to provide a more custom-made user experience when interacting with technology.

2 BACKGROUND

Newell and Gregor [166] argue that when designing technological solutions, it is necessary to consider the characteristics of all potential users. This way of thinking grew in prominence toward the end of the 20th century, when different computer manufacturing companies, such as Sun and Microsoft, introduced their "accessibility programs." These programs were directed toward the design of accessible applications to support people with different permanent impairments [166]. Several factors have pushed these developments, including demographic trends (aging population), legislative acts across different countries on the accessibility of computer technology for people with disabilities [166], and a larger focus on accessibility research within academia. Within the HCI community, Ben Schneiderman introduced the idea of accounting for accessibility in HCI research in 1986 [2, 165]. At the InterCHI '93 keynote "CHI for Everyone," Alan F. Newell emphasized the importance of taking into account the full diversity of the user population in HCI research [165]. Since then, accessibility research has established itself as one of the key research areas within the HCI community. The wide range of methods, techniques, and tools that have been developed in the field of HCI provides a rich background for the design of interactive technologies for people with disabilities [6]. Further, HCI has a rich tradition in user-centered design that encourages learning about the users and their characteristics [166], which provides an opportunity to employ HCI methods in the design of accessible technology.

As an ultimate goal of HCI is to implement successful human-computer interaction, Keates and Clarkson [114] state that to develop a solution for a wide range of user capabilities (e.g., sensory, cognitive, motor), it is necessary to understand how they interact with technology. More than two decades ago, Vanderheiden [240] outlined three paths to address the challenge of performing effective human-computer interaction: (1) by changing the user, (2) by providing the user with tools that can complement user needs, and (3) by changing the environment. These suggestions were later implemented in different design approaches aimed at creating accessible technologies.

2.1 Design Approaches

Within the domain of accessibility research, different design approaches have emerged—all of which aim to enhance the accessibility of technology. In this section, we describe the main design approaches that are either directly or indirectly related to HCI.

2.1.1 *Assistive Technology.*

This design approach took a fast-track development in the post-war era, with a predominant focus on fitting a "non-standard" user to "standard" technology [252]. The main challenge of this design principle is the assumption of an "immutable" environment that cannot be changed or adapted [252]. Assistive technology is designed specifically for people with a particular impairment in mind. As such, the presented solutions are optimized for that impairment [240], with the purpose of increasing end-user independence and improving quality of life [39].

Assistive technology has faced high rejection rates from users, as they can feel stigmatized due to device aesthetics and social acceptance [218, 240, 252]. Furthermore, assistive technology products are typically more expensive than their off-the-shelf mass market technology counterparts [240]. Similarly, Choi et al. [32] stated that assistive technology creates niche markets, thus driving technological segregation and the aforementioned increase in costs for assistive technology. Another challenge facing assistive technology is the inability to keep up with the advancements in mass-market technology [240]. For example, it often takes several delays for OS updates to reach assistive technology products as compared to their more mainstream counterparts [32].

2.1.2 *Rehabilitation Engineering.*

This design approach emerged around the same period as assistive technology, with surgeons recommending a multidisciplinary scientific and engineering approach in rehabilitation [39, 186]. Similar to assistive technology, rehabilitation engineering focuses on supporting specific needs and constrains of a unique individual [39]. Furthermore, the focus of rehabilitation engineering often involves the creation of custom add-on devices and machines specifically for rehabilitation purposes [252]. Similar to assistive technology, limitations of this approach include high cost and time investments associated with development and maintenance of such technology.

2.1.3 Universal Design. The limitations observed in assistive technology and rehabilitation engineering approaches resulted in the universal design approach [240, 252]. Universal design follows a "one-size-fits-all" principle and aims to design flexible technological solutions that can be used by users of all abilities [240, 252]. In contrast to the assistive technology approach, universal design removes the stigma from the technology by allowing users with permanent impairments to use "off-the-shelf" technology [240]. However, this feature of universal technology comes at a cost, as the price of universally designed products is typically higher due to the added complexity; however, it is important to note that its price does not depend on the user's abilities, in contrast with assistive technology [240].

2.1.4 Universal Usability. Shneiderman [219] suggested universal usability as a design approach to encompass both accessibility and usability, stating that "access is not sufficient to ensure successful usage." The aim of universal usability is therefore to design interfaces usable by the widest range of users regardless of their abilities [219, 252]. Similar to universal design, universal usability eventually aims at creating one-size-fits-all solutions without considering one specific disability [239, 252].

2.1.5 Inclusive Design. This design approach mainly focuses on the factors that lead to "design exclusions" that may occur due to biases and assumptions about user abilities [114, 252]. Consequently, Keates and Clarkson [114] argue that to support inclusive design, it is necessary to understand both end users and the tools and techniques available for designing inclusive solutions. A key element of inclusive design is the availability of "timely" knowledge about the end user, which is then translated into a design concept through numerous cycles of prototype development and testing [114]. This way the designers will minimize biases that may arise due to their own needs, capabilities, and skills [114]. However, one of the main challenges of the inclusive design approach is defining how much information and knowledge about the end user is sufficient, avoiding information overload that often leads to ineffective design practices [114]. This challenge is identified as the main reason inclusive design does not scale in terms of accommodating the needs of every individual whose capabilities are different from the established norm [252].

2.1.6 Ability-Based Design. This design principle considers the abilities of the user as its central focus [252]. To be precise, ability-based design shifts the burden of change on the system, not the user [252]. An ability-based system supports end-user interaction without requiring them to alter their bodies, knowledge, or behavior. Ability-based systems adapt their interface according to the context or user performance [252]. Although ability-based design does not necessarily pursue a goal of automatic adaptation to support user needs, recent achievements in personalized interface adaptions to surrounding context can support further advancement of ability-based design [252]. Furthermore, the adaptations remain visible to the user and can be changed at any time as required [252]. Finally, ability-based systems are encouraged to be cost effective and use readily available off-the-shelf hardware and software to remove barriers that might occur due to complexity, configuration, and maintenance of system components [252]. Nevertheless, ability-based design faces several issues that need to be addressed to implement successful ability-based solutions. These barriers include accurate and reliable quantifying of end-user performance, context sensing, and modeling of user abilities [252].

Each of the aforementioned design approaches has their own unique advantages and disadvantages, and it is inherently important for HCI researchers to find a suitable trade-off when choosing the most feasible design approach for creating accessible technological solutions. For example, Vanderheiden [240] suggests to employ a combination of universal design and assistive technology by using universal design wherever possible and commercially practical while using assistive technology wherever necessary and being advantageous to the user.

2.2 Methodological Concerns in HCI and Accessibility Research

Methodological trade-offs are a key discussion point within the HCI and accessibility communities. Although discussion of all methodological concerns is outside the scope of this article, we discuss the related work on two especially critical methodological aspects: study participants and study environments.

2.2.1 Participants. Participant populations and the degree to which they represent different user groups is an important factor in relation to the generalizability of results [214]. Furthermore, it is crucial to include representative users in accessibility research studies to understand their needs during usability studies and controlled experiments [214]. Moreover, prior work has shown that including non-representative users might lead to inaccurate conclusions [214, 215, 243]. For example, Sears et al. [215] demonstrate that, unlike able-bodied participants, users with motor impairments interrupted their dictation during vocal text entry significantly more often—resulting in a different set of commands.

Participants from different user groups also behave differently during user studies, which leads to differences in both the performance and the strategies employed by participants [243]. For instance, in a study by Ferres et al. [52], visually impaired participants used different navigation strategies when conveying knowledge about graphs from audio information, used twice as many commands to complete the task, and checked the starting point more often as compared to blindfolded sighted peers. Therefore, Sears and Hanson [214] argue that although preliminary evaluations can use participants from a non-representative user groups, studies that are eventually archived at publication venues should include representative users.

Sears and Hanson [214] also emphasize the importance of control groups in accessibility research experiments. The authors argue that the presence of control groups might provide valuable information on the effectiveness and efficiency of certain technologies or intervention techniques. Control groups allow researchers to eliminate uncertainties in results that might arise when participants are drawn from only one user group; in other words, by adding control groups to the studies, researchers can assess whether certain results hold among different user groups [214]. Nevertheless, performance of these control groups should not be taken as a standard for comparing different user groups, again due to the fact that people with different abilities might behave differently in their strategy to approach certain study tasks [214].

2.2.2 Study Environment. Within the HCI community, there exists a long-lasting and ongoing debate on the advantage and disadvantages of laboratory and field-based studies. Researchers in favor of field studies argue that laboratory studies fail to capture the complexities and richness of the real world [72, 121, 199]. However, at the same time, some prior work argues that laboratory studies can be as effective as field studies for system evaluations. For example, Kjeldskov et al. [122] presented a comparative study where a mobile system's usability was evaluated in the field (hospital) and in a laboratory environment (simulated hospital). According to the authors' results, the laboratory evaluation was able to identify almost the exact same usability problems as the field evaluation, and hence demonstrate that simulating context in the laboratory settings can be equally useful in identifying usability problems [122].

The main difference between laboratory and field studies is that laboratory studies mostly focus on evaluating certain solutions and typically involve empirical manipulations and control of the environment. Hence, laboratory studies are suitable for usability evaluations when it is needed to optimize "the certainty of the outcomes through a controlled experimentation" [237]. However, field studies aim at obtaining a complete "understanding of the application domain of the development effort" [237] and show how people understand and use technology in their own terms and for particular situated purposes [127]. It has previously been shown that field studies are commonly used in three situations: (1) to observe and understand HCI professionals in the field, (2) to understand users working with emerging technology, and (3) as a starting point to design novel interactions [237].

Although laboratory studies are excellent at identifying usability problems, they perform poorly in understanding context of use [199]. It is therefore important to conduct field studies, as we need to understand how technology is used and adapted in real-world settings [121, 199]. Furthermore, Kuutti and Bannon [127] argue that real-life scenarios should be studied where they occur (i.e., in a naturalistic setting), as laboratory studies aimed at gathering knowledge on how certain interfaces are used have limited applicability [127, 229]. Hence, field study research should be focused to better reflect the complexity of HCI in a real-world setting [199]. As there is no clear answer as to whether laboratory studies are better than field studies, Kjeldskov and Skov [121] suggest that HCI researchers should rather focus on *when* and *how* to conduct laboratory or field studies. The authors also suggest that HCI researchers should run "truly wild and longitudinal" field studies to fully embrace real-world settings [121].

Given the growing importance of accessibility research, this article aims to quantify and increase our understanding on the methodological decisions made by accessibility researchers investigating motor impairments. By providing an overview of the strengths and weaknesses in our research practices, it is our hope to support the further development of accessibility research, which can lead to the development of better assistive technology.

3 METHODOLOGY

We conducted an extensive systematic literature review on studies aiming to enhance the accessibility of technology for motor-impaired users. We conducted our search on two main digital libraries in the computer science domain that provide a rich overview of peer-reviewed articles in our research community: *ACM Guide to Computing Literature* (hereafter, ACM Digital Library) and *IEEE Xplore*. Our search query was conducted using an "inclusive or" for the terms "motor impairments," "motor-impaired users," and "motor disabilities" combined with an "and" operator for the terms "accessibility" and "design" subsequently to ensure that the search returns papers conducted in the accessibility domain of the HCI research. Furthermore, our search was run on both full text and metadata of the publication (e.g., title, abstract, keywords) to ensure that we have a thorough and complete overview of articles published in this research domain. In addition, we restricted our search to consider publications between 2000 and 2020 to (1) guarantee a focus on modern technology and (2) examine the changes in conducting accessibility research over a period of two decades.

In total, our search query returned 966 papers from both the ACM Digital Library and IEEE Digital Library. Each of these papers was analyzed individually by one of the authors of this literature survey according to the inclusion criteria. First, we identified and excluded extended abstracts papers (e.g., poster, workshop, tutorial) from the list of 966 papers, resulting in 752 papers. We then manually analyzed each publication and excluded the papers ($N = 128$) that were not relevant to motor impairments but to some other impairments (e.g., visual, cognitive). We also excluded publications ($N = 559$) that were not directly relevant to motor impairments but mentioned the applicability of the technology, study, and so forth for motor impairments in the "future work" or "discussion" sections of the publications. We also excluded papers that look at the combination of the impairments (e.g., autism resulting in motor impairments). Finally, we removed papers that did not report empirical studies ($N = 33$). Following this curation strategy, we identified a total of 177 relevant papers that we explore in this literature survey.

4 RESULTS

We analyzed the number of papers published between 2000 and 2020, and found that the number of studies is substantially higher in the second decade (2011–2020) than the first (2000–2010)—see Figure 1.

Our analysis identified 177 papers totaling 228 studies. There is an average of 1.3 studies reported on each paper (in line with local HCI standards reported previously [24]), with the large majority of papers having 1 study (135), 33 papers with 2 studies, and 9 papers with 3 or more studies. A full overview of the studies and their details can be found in Table 2 in the appendix. In our subsequent analysis, we assess and report on each study rather than on each paper to capture the specifics of each study contribution.

4.1 Devices Used in the Studies

We started by examining the type of devices used in the different studies. Typically, these devices were used to evaluate accessible solutions (i.e., interfaces, apps) for motor-impaired users. From our analysis, we discovered that starting from year 2000 up until recent years, most studies (73 in total, 41.2%) were focused on building accessible solutions for desktop computers; however, this interest of the community has decreased in the past few years. In addition, 16 studies (9.0%) developed accessible solutions for desktops using an eye-tracker. The growing popularity of mobile devices has led to a shift in focus within motor-impaired accessibility research. For example, 12.4% of all studies (22 of 177) focused on developing accessible interfaces for smartphones, and 5.1% of studies (9 in total) worked on creating accessible interfaces for tablets, many of which were conducted in recent years. Furthermore, it is worth noting that wearables have been increasingly used in the past decade, resulting in the total of 18 studies (10.2%). Finally, a fair amount of other technology is used for accessible research. According to our analysis, a total of 39 studies (22.1%) used other technology including, but not limited to, wheelchair joysticks, various consoles and haptic devices, human-robot interfaces, and tabletops. A summary of these results is presented in Figure 1.

We then examined the category of devices marked as "other" in more detail. Of 39 studies that have developed accessible interfaces for other technology, 10 papers worked on enhancing the accessibility of wheelchairs (e.g., input for wheelchairs) [25, 27, 67, 69, 150, 154, 155, 213, 235, 254], 5 papers worked on motion sensing devices (e.g., Kinect, LeapMotion) [41, 111, 126, 144, 206], 3 papers with game consoles (e.g., Nintendo Wii) [40, 88, 95], and 2 papers worked with tabletops [13, 140]. Furthermore, some studies developed new interfaces, including creation of haptic devices (4 papers) [93, 123, 128, 205] and prosthetic arm (1 study) [92], and 1 universal interface that can be used for mobile devices, game consoles, and eye-trackers [236]. Furthermore, 7 papers created human-robot interfaces to assist motor-impaired users [17, 43, 46, 99, 108, 116, 196].

4.2 Study Parameters

Based on the information available in the publications, we identify common study parameters in motor impairment research studies.

A large portion of the studies (79 of 228, 34.6%) was conducted in a laboratory environment, and 59 studies (25.9%) were field studies (e.g., participants' home, care center, hospital). Unfortunately, the remaining 90 studies (39.5%) did not explicitly state whether the study was conducted in laboratory or field settings; however, from the context of the papers, the reader can sometimes infer if the study was either a field study or was conducted in the laboratory. Nevertheless, as it was not

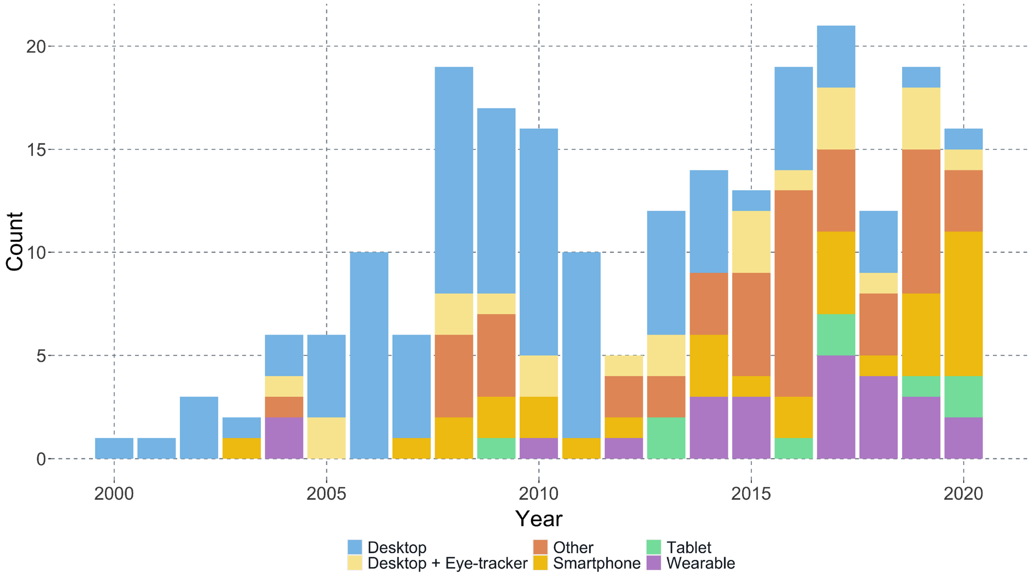

Fig. 1. Device prevalence in analyzed studies.

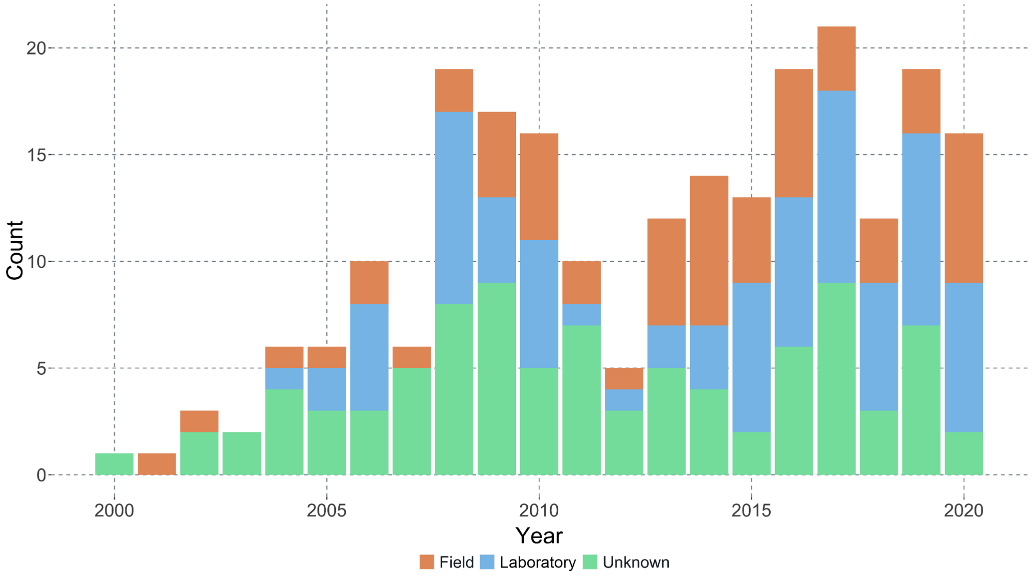

Fig. 2. Studies overview.

obvious to us how to determine the type of the study from the papers, we did not classify them in this survey. These findings are summarized and presented in Figure 2.

We then examined the type of analysis conducted in the selected studies. A total of 104 studies (45.6%) employed a mixed-method analysis in their study, whereas 29% of the studies (66) used a purely quantitative approach and 58 studies (25.4%) utilized a purely qualitative data analysis approach. Our results show that the number of studies that employ quantitative analysis is greater than the number of studies that use qualitative analysis. A similar trend has been reported in local HCI standards reported by Caine [24].

We followed up by analyzing the study duration of the published studies. To keep consistency in our data, we decided to classify the duration of the studies as follows: a short 1-day study (e.g., 45-minute-long experiment) vs. a longitudinal study (e.g., study conducted over the course of several days). Furthermore, some studies reported their duration in sessions (e.g., five sessions 1 hour long each). Therefore, to simplify the analysis of study duration, we assumed one session to be a 1-day-long experiment; hence, if the study reported eight sessions, we considered it to be an 8-day study. The average duration of a study is $M = 5$ days with a standard deviation of $SD = 21$, and a median of $M = 1$ day. A total of 173 studies (75.9%) report a short 1-day study, whereas 47 papers (20.6%) report conducting a longitudinal study that continued for several weeks. Unfortunately, in some cases, we were not able to determine if a study was longitudinal or not (8 studies, 3.5%).

4.2.1 Baseline Details. Next we analyzed the baseline details of the studies presented in this literature survey. Most studies (123, 54.0%) either do not report baseline details they used in the experiment (21, 9.2), or it was not relevant to have a baseline condition in the study (102, 44.8%) (e.g., if the study was focused on eliciting gestures to interact with technology, like the study of Vatavu and Ungurean [241]). The remaining 105 studies (46%) described their baseline information with 47 of 228 studies (20.6%) reporting use of conventional technology (e.g., [163]) or an existing method (e.g., [246]) as a baseline condition (e.g., a regular computer keyboard vs. custom-built text entry interface). Furthermore, 28 studies (12.3%) did not have a baseline per se but compared different conditions between each other. In addition, another 14 studies (6.1%) used a controlled interaction method for a baseline (e.g., speech input vs. custom-designed interaction technique). Interestingly enough, 15 studies (6.6%) used performance of the able-bodied participants as the baseline. Finally, 1 study (0.4%) used performance reported in external studies as their baseline condition [197].

4.2.2 Study Tasks. We then analyzed the type of tasks used in the studies to understand if there are established standards for quantifying performance of participants. Twenty-three of 228 (10.1%) studies did not quantify participants performance using tasks, and usually these studies based their results on either interviews or surveys. The remaining 205 studies reported using at least one task to quantify the performance of participants. As the naming of the tasks across the studies was quite diverse, we grouped the tasks according to their similarities. Two authors of the paper categorized the tasks from the entire dataset according to their similarities. This way, we grouped tapping, selecting, and clicking tasks under "target acquisition." Similarly, if the participants had to perform any tasks to change or work with the interface of the technology, we grouped them under "interface manipulation." Other groups that emerged after our categorization are "physical exercise activity" for the tasks where participants were ask to perform a physical activity (e.g., walk in a straight line), "hand manipulation" for the tasks where participants had to perform any sort of hand manipulation (e.g., close and open the wrist), and "playing games" for the studies where participants had to play a game. This categorization revealed a taxonomy with 34 tasks that were used across the 205 studies that measure functional capabilities of participants. The complete list of the tasks is presented in Table 1. We then calculated Cohen's kappa [146] to examine the interrater reliability, which showed strong agreement between the raters ($\kappa = 0.90, p < 0.01$). The games were quite diverse in the studies; therefore, we did not specify categorization according to the game type. Furthermore, the tasks that required completing daily online tasks, such as sending an email, checking for weather, and taking pictures, we grouped them under the "daily online activities" category. For each task, we defined measure variables that were quantified in the studies. We present a full overview of the tasks and their measure variables in Table 1.

Table 1. Tasks Overview

Tasks	**Measure Variables**	**Papers**
Area pointing	Perceived cognitive workload, model fit, task completion time, error rate, movement time, throughput, subjective satisfaction, perceived ease of use, perceived speed, path length, target re-entry, task axis crossing, movement direction changes, orthogonal direction changes, movement variability, movement error, movement offset, number of submovements, maximum velocity, normalized time of maximum velocity, maximum acceleration, normalized time of maximum acceleration, maximum absolute jerk, total square integrated jerk	[54, 63, 249, 250]
Calibration	Offset magnitude	[47]
Creation of vocal commands	Lexical density of corpus, common words	[201]
Daily internet activities	Perceived comfort, perceived ease of use, error rate, movement time, perceived usefulness, task completion time, system usability, perceived cognitive workload (NASA-TLX), number of clicks, cursor positioning time	[5, 8, 51, 86, 139, 148, 200, 262]
Dragging	Task completion time, error rate, movement time	[54, 55, 233]
Foot manipulation	Toe-tap rate, toe-raise rate	[35]
Gesture input	Path length, gesture completion time, line steadiness, task completion time, error rate, perceived ease of use, perceived learnability, task completion success rate, perceived difficulty, classification accuracy, dwell time, perceived cognitive workload, perceived physical workload, usability	[12, 25, 26, 29, 45, 69, 91, 106, 107, 230, 241]
Goal crossing	Movement time, throughput, error rate, subjective satisfaction, perceived ease of use, perceived speed, path length, target re-entry, task axis crossing, movement direction changes, orthogonal direction changes, movement variability, movement error, movement offset, number of submovements, maximum velocity, normalized time of maximum velocity, maximum acceleration, normalized time of maximum acceleration, maximum absolute jerk, total square integrated jerk	[249, 250]
Hand manipulation	Task completion time, duration of pauses, movement direction change, total motion time, average motion time, total pause time, average pause time, motion variability, motion distance, motion amplitude, physical performance	[43, 92, 169, 188]
Indoor navigation	Error rate, system usability, perceived stress, number of uprising steps, task completion time	[126, 152, 196]
Information search	Task completion time, system usability, perceived cognitive workload (NASA-TLX), movement time, subjective satisfaction, perceived productivity, perceived effectiveness	[22, 148, 180]
Input invention	Ease of use, task completion success rate, perceived difficulty	[25, 26, 76]
Interface manipulation	Task completion time, movement time, error rate, perceived ease of use, perceived usefulness, subjective satisfaction, classification accuracy	[33, 36, 45, 63, 125, 157, 173, 202, 262]
Long press	Task completion success rate	[176]
Map navigation	Task completion time, false-positive clicks, unregistered commands, error rate, subjective satisfaction	[18, 33]
Object manipulation	Classification accuracy, task completion success rate, cross-entropy loss, number of switches of control mode, selection time, perceived ease of use, user preference, ease of control, movement distance, force, speed, task completion time, error rate, perceived comfort, perceived fun, perceived difficulty	[31, 99, 108, 116, 123, 140, 150, 194, 195]
Painting/Drawing	Task completion time, dwell time, perceived ease of use, perceived learnability, task completion success rate	[21, 83, 96, 98, 177]
Peg test	Path-length ratio, movement error, movement direction change, line steadiness	[93, 94]
Physical exercise activity	Stride length, step length, physical performance, system usability, perceived comfort, classification accuracy, perceived cognitive workload (NASA-TLX), error and speed ratio, motion duration, motion steadiness, motion accuracy	[11, 40, 118, 128, 145, 206, 259]
Pinching	Task completion success rate	[176]
Play a game	Perceived ease of use, perceived learnability, perceived comfort, perceived speed, perceived enjoyment, game specific parameters, time to touch-down, time to touch-up, offset magnitude, touch duration, movement direction changes, touch location, game-specific parameters, perceived fun, perceived fairness, physical performance, perceived comprehensibility, visual quality, perceived correctness, likelihood to play, motivation, perceived boredom, activity level, disinterest, usability, distraction time, attention time, output score, task completion time	[10, 41, 44, 66, 69, 88–90, 105, 109, 119, 135, 144, 153, 171, 213, 222, 242]

(Continued)

Table 1. Continued

Tasks	Measure Variables	Papers
Programming (writing/editing code)	Task completion time, number of keypresses	[170, 201]
Rotation	Task completion success rate	[176]
Scrolling	Task completion success rate	[176]
Speech input	Task completion time, perceived ease of use, perceived learnability, perceived intuitiveness, subjective satisfaction, perceived effectiveness, task completion success rate	[21, 65, 95, 95, 138]
Steering	Task completion time, error rate, movement time, throughput	[54, 84]
Swiping	Path length, gesture completion time, line steadiness, perceived ease of use, task completion success rate	[138, 176, 241]
Target acquisition	Perceived cognitive workload, model fit, task completion time, perceived ease of use, error rate, movement time, throughput, subjective satisfaction, perceived speed, path length, target re-entry, task axis crossing, movement direction changes, orthogonal direction changes, movement variability, movement error, movement offset magnitude, number of submovements, maximum velocity, normalized time of maximum velocity, maximum acceleration, normalized time of maximum acceleration, maximum absolute jerk, total square integrated jerk, perceived learnability, perceived memorability, perceived accuracy, perceived effort, perceived frustration, perceived fun, perceived naturalness, perceived comfort, perceived intuitiveness, perceived effectiveness, click accuracy, press accuracy, release accuracy, distance to target, number of touches, time to touch-down, time to touch-up, dwell time, offset magnitude, offset direction, accidental clicks, number of voice commands, touch duration, task completion success rate, number of unsuccessful clicks, missed targets, cursor position corrections, perceived cognitive workload, time to mouse down, classification accuracy, perceived system responsiveness, perceived consistency, perceived predictability, number of pauses, duration of pauses, path-length to axis-length ratio, physical workload, effective target width, perceived fatigue, perceived attentiveness, perceived prompting levels, curvature index, streak size, streak sum	[15, 19, 34, 48, 50, 53–55, 58, 62–64, 78, 79, 81, 82, 84, 86, 95, 98, 100, 101, 104, 107, 115, 132, 138, 139, 143, 149, 151, 152, 159, 161–163, 174, 176, 178, 179, 181, 183, 195, 197, 203, 233, 235, 248, 250]
Text entry	Task completion time, perceived ease of use, typing speed, error rate, communication speed, subjective satisfaction, perceived learnability, perceived intuitiveness, perceived effectiveness, number of gestures per character, number of keystrokes per character, number of corrections, number of deletions, perceived cognitive workload (NASA-TLX), perceived comfort, accuracy (minimum string distance), uncorrected error rate, corrected error rate, dwell time, total error rate, user experience, perceived speed, perceived accuracy, perceived likeability, total number of words, total number of characters, total number of alphanumeric characters, total number of non-alphanumeric characters, total number of space characters, total number of capital letter shifts, total number of alphanumeric keys in input, alphanumeric keystrokes per character, keystrokes per character, alphanumeric keystroke saving rate, typing speed improvement, potential keystroke saving rate, actual keystroke saving rate, prediction utilization, perceived usefulness, perceived distractiveness, perceived fatigue, typing variability, word classification accuracy, character classification accuracy, human readability accuracy, ballistic phase movement time, corrective phase movement time, total movement time	[7, 16, 38, 49, 74, 77, 80, 113, 124, 132, 137, 138, 141, 150, 156, 160, 163, 175, 184, 193, 204, 224, 231, 232, 234, 246, 253–257, 260, 261]
Trajectory tracking	Perceived difficulty (NASA TLX), physical performance, classification accuracy, line steadiness, task completion time, accuracy	[85, 91, 140, 195, 205, 258]
User=specific free=form task	Session length, perceived enjoyment, perceived frustration, perceived fatigue, number of button activations, number of special effects activations, distance to target, task completion time, subjective satisfaction	[42, 143]
Virtual navigation	Time per keystroke, error rate, task completion time, perceived comfort, perceived fun, perceived difficulty	[57, 150]
Visual search	Perceived learnability, perceived memorability, perceived accuracy, perceived ease of use, perceived effort, perceived frustration, perceived fun, perceived naturalness, task completion time, streak size, streak sum	[19, 64, 152, 181, 236]
Web navigation	Task completion time, false-positive clicks, unregistered commands, error rate, system usability, movement time, touch-down time, distance to target, target re-entry, throughput, curvature index	[18, 179, 180, 221]
No task was used to measure performance	NA	[13, 17, 27, 46, 67, 75, 97, 111, 112, 154, 155, 158, 164, 187, 198, 220]

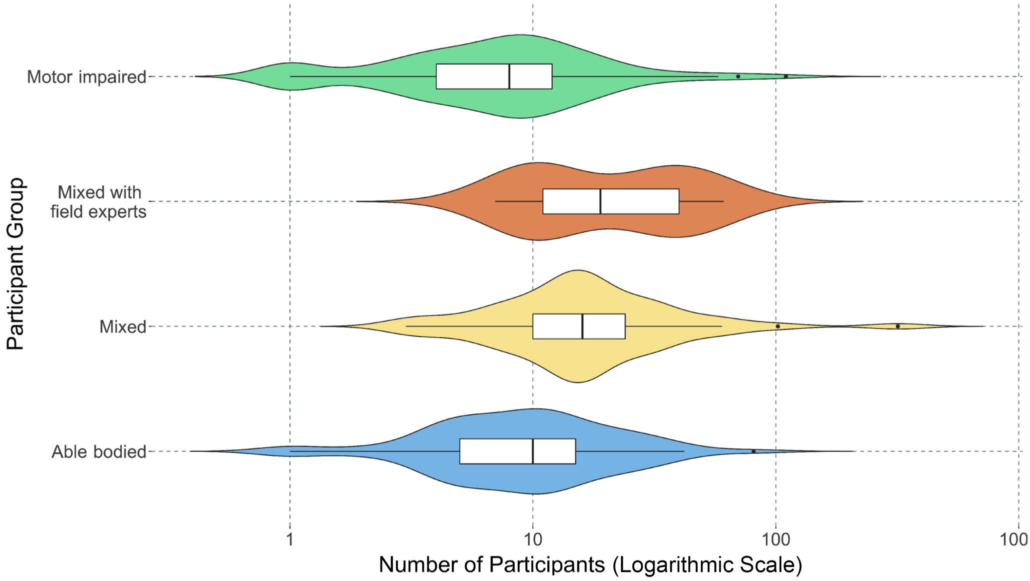

Fig. 3. Device prevalence in analyzed studies.

4.2.3 Participants. The number of participants varied reasonably without drastic outliers in the analyzed papers ranging from 1 to 318 ($SD = 25$) with the mean of $M = 15$ and the median of $Med = 10$. These results are in line with the local standards in the HCI community with the common sample size of 12 participants; however, they are on a lower side of the participant sample size [24].

Of these 228 studies, 91 (40%) were conducted strictly with motor-impaired participants, 73 (32%) were performed strictly with able-bodied participants, 52 (22.8%) studies recruited both able-bodied and motor-impaired participants, 10 (4.4%) studies included field experts as participants (therapists, rehab specialists), 1 study (0.4%) reported recruiting one vision-impaired participant, and 1 study (0.4%) did not report if their participants were able bodied or motor impaired. Furthermore, our analysis shows that 79 studies (34.6% of all studies, 55.2% of studies with motor-impaired and mixed-participants groups) recruited participants with different diagnosis. Next we analyzed if the sample size of the study was different depending on the recruitment group (e.g., able-bodied, motor-impaired, or mixed-type participants). A one-way analysis of variance test showed a statistically significant difference in sample size and participants type ($F(3, 220) = 4.91, p < 0.01$). A Tukey HSD post hoc comparison test (with Bonferroni corrections) reveals that an average sample size in studies with mixed participants is significantly greater than the average number of participants in studies with only motor-impaired participants ($p < 0.01$) or able-bodied participants ($p = 0.02$). Our results did not reveal any other statistically significant difference between other participant groups. We excluded the study that reported recruiting one vision-impaired participant and 2 studies (from the same manuscript) that did not report their participant group from this analysis. These results are presented in Figure 3.

Then we analyzed participant group versus study location. A chi-square test of independence showed that there was a significant association between the study location and participant group ($\chi^2(4, 228) = 48.14, p < 0.001$). The number of motor-impaired participants and the number of participants including field experts are significantly higher in field studies, whereas the number of able-bodied participants is significantly higher in laboratory studies. The results of these findings are presented in Figure 4.

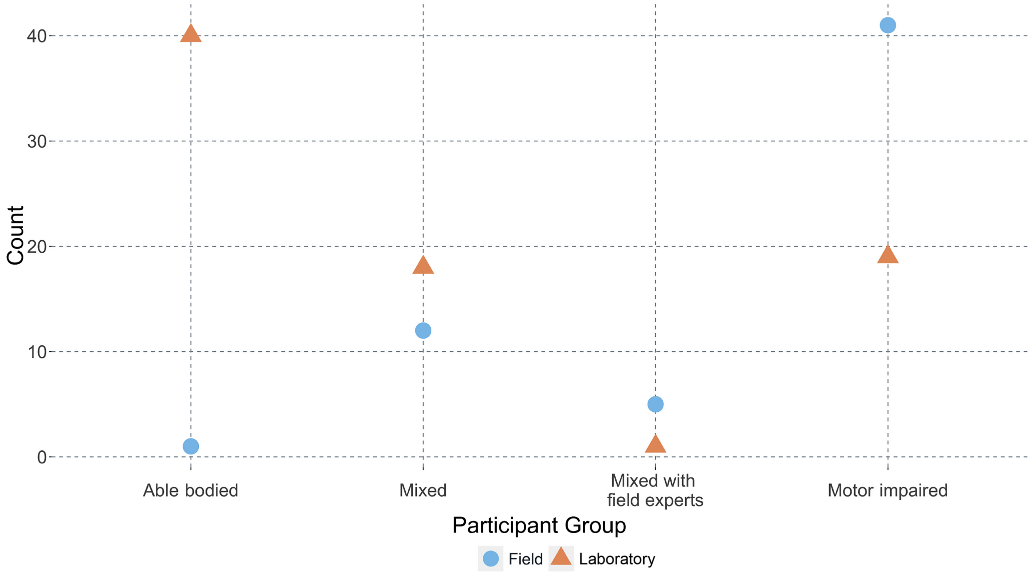

Fig. 4. Participant prevalence within the study environment.

Similarly, we analyzed device prevalence versus study location to understand if certain technology was tied to the laboratory or an in-the-wild environment. A chi-square test of independence showed that there was a significant association between the study location and device category ($\chi^2(5, 228) = 13.86, p = 0.02$). Our results demonstrate that a desktop with an eye-tracker is more expected to be in the laboratory setting, whereas equipment defined in the "other" category is expected to be used in field studies. This is not surprising considering that eye-trackers are mostly used in the laboratory environment because of their cost and configuration difficulties [185]. Furthermore, we categorized wheelchairs mostly as "other" equipment, and participants were using their wheelchairs while being recruited in in-the-wild studies. These findings are presented in Figure 5.

We also analyzed participant impairment information. The most common motor impairment diseases affecting participants of the studies were cerebral palsy (62 studies), spinal cord injury (30 studies), Parkinson's disease (24 studies), multiple sclerosis (16 studies), muscular dystrophy (24 studies), and post-stroke hemiparesis (25 studies). Other diseases were presented in fewer than 10 studies. We subsequently grouped participant impairment information into categories and analyzed categories information. We used categorization provided by Utah State University's Institute for Disability Research, Policy, and Practice [1]: traumatic injuries (e.g., spinal cord injury, loss or damage of limb(s)), congenital conditions (cerebral palsy, muscular dystrophy, spina bifida), diseases correlated with age (e.g., arthritis, Parkinson's disease, essential tremor, multiple sclerosis), and diseases with a mysterious cause (e.g., ALS). We added an additional category for other impairments not matching any of the preceding categories (e.g., blindness). To categorize the impairments, two authors read through the list of impairments collated from the literature review. Then, the two authors completed the categorization of the impairments independent from each other. Once the categorization was finished, we performed interrater reliability analysis using the kappa statistics to determine consistency among the two raters, which showed strong agreement between the raters ($\kappa = 0.81, p < 0.01$). We then performed analysis of the distribution of these categories among our sample. A one-way analysis of variance test did not show a statistically

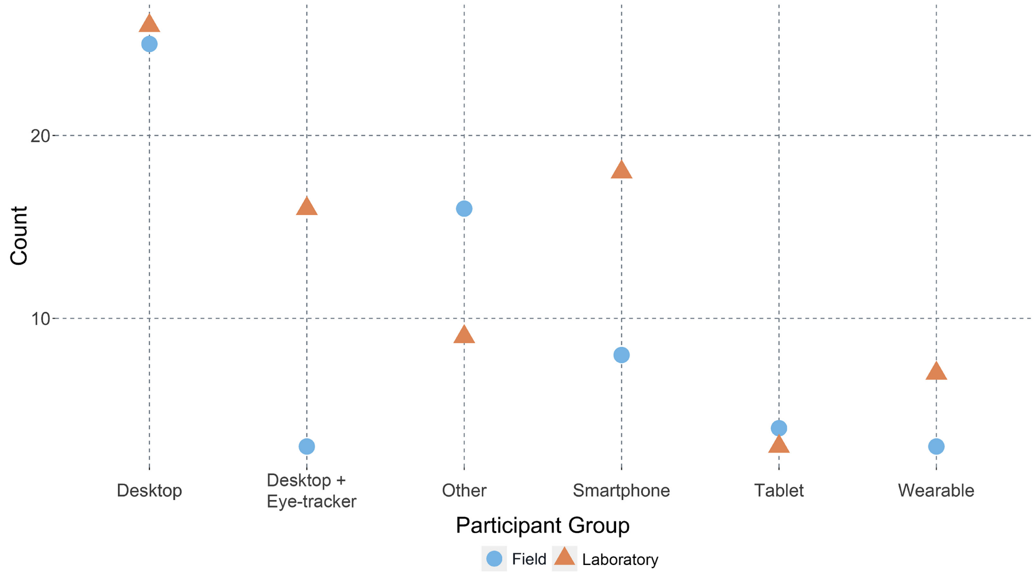

Fig. 5. Device prevalence within the study environment.

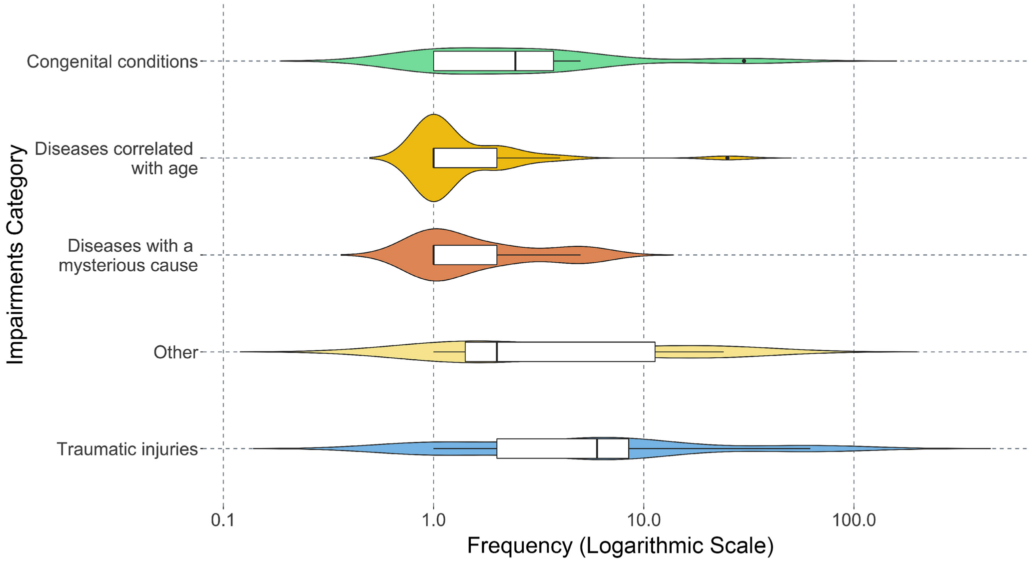

Fig. 6. Participant impairment categories distribution.

significant difference in the distribution of the preceding categories within our participants' sample ($F(4, 60) = 2.50, p < 0.05$). These findings are presented in Figure 6.

It is important to note that the studies analyzed in this survey recruited participants from a range of diagnoses (e.g., participants with cerebral palsy as well as participants with Parkinson's disease). For this reason, the total number of studies might not add up to the number mentioned in the preceding paragraph. Unfortunately, 18 studies do not provide details of their participants' impairment details.

As it is common to give incentives to participants in user-subject studies, we analyzed how incentives are being handled in the studies aimed at investigating motor impairments research. Unfortunately, a large portion of 186 studies (82.0%) did not report any detail on participant incentive—only 42 studies (18%) provided this information. Of these 42 studies, 30 studies compensated their participants with cash, whereas 6 studies rewarded their participants with gift cards and vouchers (5 studies with a shopping voucher and 1 study with a lunch voucher). Furthermore, 2 studies reimbursed their participants with movie tickets; 1 study provided participation in a gift voucher raffle; 2 studies explicitly stated that no reward was provided for participants, and, finally, 1 study did not specify the reimbursement amount.

5 DISCUSSION

5.1 User Representation in Accessibility Research

Our results show that 32% of the studies were conducted with able-bodied participants. Such an outcome is predictable and understandable given the difficulties of recruiting participants from the permanently impaired user group [214]. Nevertheless, such an approach is perilous, as it might lead to inaccurate conclusions and missed insights [214]. A decade ago, Sears and Hanson [214] argued that non-representative users might be acceptable for preliminary evaluations but that studies being published in archival venues should be conducted on representative users. Several examples in the literature have shown that able-bodied participants and permanently impaired participants behave differently during the studies and their strategies differ in their approach to resolve the problem [215, 244]. Such differences exist even among participants from permanently impaired user groups, as research has shown that people who were born with a certain condition perform differently as compared to people who developed the condition during their life [87].

Our results also show that the average number of participants per study was $N = 15$, which can be considered in line with the HCI standards [24]. However, applying a traditional statistical analysis approach might be challenging for such a number of participants [214]. Therefore, there is a need for alternative solutions when conducting experiments in accessibility research, such as single-subject experiments [217] and repeated-measures design [225].

Another common trend observed from our analysis is that almost a quarter of the studies mostly use a combination of able-bodied and permanently impaired users ($N = 52, 22.8\%$). Sears and Hanson [214] argue that failing to identify significant differences in performance when comparing the two user groups does not mean that both groups are equivalent, as details of how the tasks were completed were not taken into account.

In addition, our analysis shows that it was relatively common in our sample (34.6% of all studies) to recruit participants with different impairment diagnoses [1], even though the distribution of the categories in study samples was not statistically significant. Although individual papers typically focus on one or a small number of impairments, we argue that a higher level understanding of the categories studied in HCI-driven accessibility research is of critical importance. The categorization of motor impairments could allow for a more thorough investigation of the motor impairments phenomenon from an HCI research perspective and lead to crossovers in lessons learned between different impairments. For example, prior research has shown that people with congenital conditions have a higher disability self-concept and are more adaptive to using technological solutions as compared to people with acquired disabilities (e.g., age-related disabilities) [20]. Such high-level differences between different categories of impairments are rarely synthesized in HCI literature.

Furthermore, our results show that one study among those with motor-impaired participants did not report impairment details of their participants. However, providing a medical diagnosis is an important detail when describing the participant sample, as it might directly define physical capabilities of participants [214]. The diagnosis often provides information on the challenges an individual might experience when performing certain activities/tasks [214]. This information in combination with other user details (technology used, user capabilities, background, and experience) might facilitate the generalizability of the findings [214].

5.2 Measuring Functional Capabilities

Our results also show that most of the studies (90%) quantified functional capabilities of the participants using different variables throughout the taxonomy of 34 tasks. Our results show that most common tasks used in the studies were target acquisition and text entry (Table 1).

Price and Sears [189] highlight the necessity of providing an accurate and repeatable method to assess a user's functional capabilities in the context of HCI and accessibility research when interacting with technology. The authors argue that such an assessment tool will assist in better user categorization as well as matching the uses with appropriate technology [189].

Furthermore, Price and Sears [189] demonstrate that there is a need to categorize functional evaluation metrics based on what they measure. The authors provide an example of task completion time being one of the evaluation metrics of functional capabilities of users when interacting with technology [189]. Furthermore, the authors demonstrate that movement is also an important aspect of measuring capabilities [189]. In particular, such details of movement as path followed in target acquisition tasks [136, 251] as well as variability in task completion that has been shown to be one of the most used metrics to measure an individual's capabilities [189].

Price and Sears [189] mention an important issue of established measures providing different assessment results. In their study, the authors show that examining functional capabilities using PB-FACT (Performance-Based Functional Assessment for Computer Technology) scores [189], self-reported survey results, and gold standard observer ratings show different scores in measuring user capabilities. For example, all self-reports indicated the participants could complete the tasks without any difficulties, whereas PB-FACT scores and gold standard observer ratings indicate that participants experience some level of difficulty during task completion [189].

Furthermore, functional capabilities in current research practices are mostly assessed under controlled laboratory settings and have been shown to be non-representative of real-world performance [101]. Therefore, Gajos et al. [61] argue that the modeling of functional capabilities of users should be based on the data collected unobtrusively during a user's free interaction with technology.

5.2.1 *Games for Rehabilitation Purposes.*

Twenty-six studies (18 papers) have reported using a game as a task to measure functional capabilities of users (Table 1). This type of task was the third most popular after target acquisition and text entry used across 228 studies reported in 177 papers analyzed in this survey. Our results show that integrating games to the tasks in accessibility research studies is quite common and can pursue rehabilitation aims.

According to our results, every third study (eight studies across six papers [10, 41, 44, 109, 119, 144]) used games for therapeutic rehabilitation purposes. The literature has presented examples where games have been used for therapeutic purposes. For example, Fukamoto [60] successfully leveraged games for neurorehabilitation, as they provided a "Fun" incentive for users with foot drop syndrome. Similarly, research has also shown that virtual reality games have become one of the strategic therapies to encourage movement in motor-impaired users (e.g., users with cerebral palsy [130], spinal cord injuries [120], essential tremor [37]). The same applies to robot-mediated therapies that have gained an increased popularity in the rehabilitation process for motor-impaired individuals [147].

Furthermore, the literature has shown that integrating game elements into wheelchairs established positive relationships between the user and the wheelchair [68]. This is particularly important for novice users, as gamification allows them to accept wheelchairs as an enabling and fun technology rather than a restriction of their independence [68]. Moreover, the authors argue that wheelchair-based game controls could potentially assist in developing wheelchair skills, such as improving abilities to navigate in the environment and extending functional independence [68]. Nevertheless, it is important to remember that when using games to measure functional or perceptual capabilities of participants, the quality of game design has an effect not only on game experience but also on the quality of scientific assessment [238]. Therefore, a better quality of game design leads to more accurate scientific measurements and hence should be accounted in research to achieve robust research practices.

5.3 Barriers to Accessibility Research and Development

Next we outline the main barriers to conducting accessibility research and designing accessible technology.

5.3.1 *Recruitment and Logistics.*

From a research perspective, it is challenging to recruit more than 10 participants with disabilities to evaluate a new design or piece of technology [142]. Having bigger samples would definitely improve the representation of the population; however, it is still not guaranteed, as the heterogeneity of the population is highly varied [142]. Furthermore, it might be difficult to perform longitudinal studies and data collection due to accessibility problems that arise from participant fatigue, reduced speed, and performance [142].

Throughout the development of accessibility research and assistive technology, several methods have emerged to overcome the preceding issue [142]. For example, simulation is one of the techniques that allows to mimic certain impairments, such as blindfolding to replicate the experience of those who have visual impairment [142]. However, in most cases, simulation fails to reproduce the true experience of an impairment and raises ethical concerns [117].

Nevertheless, simulation provides an inexpensive and quick way to evaluate the interface and to ensure that it would not cause any issues to the participants during the study [142]. Hence, it can be used as an initial step before involving participants with disabilities to save time and resources.

Several research projects have demonstrated that instead of simulation, data corpora can be used [102, 142]. The advantage of using pre-existing datasets to test hypotheses is that it is more realistic, as it includes data from participants' daily experience [142]. One more issue might be the duration of the studies. Bannon [14] argues that trials of a few hours, or even days, do not allow the observation of issues of long-term use and habituation.

5.3.2 *Cost.*

One of the key challenges of designing accessible technology is its cost inefficiency [223]. This mostly occurs because most technological solutions are designed to address the needs of able-bodied users [70]; hence, designing technology for a permanently impaired user group needs several levels of customization and implementation of specific design tools [223].

Moreover, several studies have shown that individuals with permanent impairments prefer to use mainstream technology rather than specialized devices due to several factors, including, but not limited to, social and financial components [112, 190, 218]. Furthermore, higher costs of accessible technology might lead to discrimination and isolation of users due to their economical limitations [6].

Therefore, accessible and assistive solutions should not be expensive by the time they are ready for market production. Nevertheless, Newell and Gregor [166] argue that provision of information technology is not necessarily expensive if accessibility is considered at an early stage of the design.

In terms of creating accessible software solutions, it is easier to create designs accounting for accessibility from its initial states rather than incorporating accessibility into a finished product.

5.3.3 Abandonment. Despite the high demand for assistive technology devices, the abandonment rate of assistive technology is quite high [103]: 29.3% overall [182], 8% for life-saving devices [212], 36% for dressing aids [212], 61% for crutches [182], and even 75% for hearing devices [182]. To combat these high levels of abandonment, the literature suggests a "do-it-yourself" approach in designing and customizing assistive technology, as it has been shown that users of assistive technology have concrete modification ideas that are affordable both in terms of cost and implementation [103].

One approach to custom modifications is the involvement of the users of assistive technology in the design and creation process [103]. Several initiatives already exist to support collaborative design and development of assistive technology. For example, the Open Prosthetics Project[1] is a community that supports open source education and collaboration between users, designers, and funders to develop and share prosthetic innovations [103]. To succeed, such online communities need to be well known within the relevant user space, enable a low-barrier to entry for making contributions, and should be easily found via online search [103].

Further, existing limitations in accessibility impose different problems on different user groups, as it has been shown that people who do not have access to technology may experience the adverse effects of a digital divide [56]. Therefore, the development of accessible technology has to be approached from a range of perspectives. Abascal and Nicolle [6] therefore argue that it is necessary for social and political factors to influence the development of accessible technology, as it does not evolve by itself.

Another well-known challenge within the HCI community is the abandonment of research prototypes following the completion of an experiment [227]. It is common for research prototypes to be taken back to the laboratory, and then redeployed with a different sample of participants, or in cases of where prototypes are left with participants, that no further technical support is provided. Hence, the initial users of the prototypes are left on their own after the project concludes [227]. Such a practice can be unfair to the participants who commit their time and efforts to the experiment [129]. This is particularly harmful to participants with permanent motor impairments and their caregivers, as their physical constraints result in extra effort required to participate in the study, reach the study site, and complete study tasks. Furthermore, it is problematic to provide participants with permanent motor impairments with technological solutions that potentially improve their quality of life and subsequently remove this piece of assistive technology from their lives. Therefore, the research community needs to break with the trend of abandoning research prototypes without a longer-term plan for the participants if we as a community want to set and follow good research practice.

5.3.4 Situational Impairments. More than two decades ago, Newell and Gregor [166] talked about disabling environments that can potentially impair human-computer interaction. The authors provide examples of different situations such as a cold environment where people are required to wear protective clothing and gloves that reduce dexterity of their motor functions similar to those of permanent motor impairments. Later, Sears et al. [216] coined a term for these temporal impairments, referring to them as **"Situationally-Induced Impairments and Disabilities" (SIIDs)** or *situational impairments* [61].

Although the focus of our survey was not on situational impairments, it is important to consider SIIDs when designing accessible technology—the reason being that situational impairments

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[1] http://www.openprosthetics.org.

affect users of all abilities, and furthermore, they worsen the experience of permanently impaired users [110, 210, 247]. Research has shown that different SIIDs such as walking [71], ambient noise [211], dim ambient light [209], encumbrance [168], and cold temperatures [73, 207] have a negative effect during mobile interaction. Furthermore, accessibility issues of technology might be exacerbated for permanently impaired users by situational impairments [110, 247].

Hence, several experts in accessibility and HCI have stated that designing solutions to account for SIIDs can lead to new interface ideas that can also accommodate permanently impaired users [71, 166, 208, 247], and vice versa, designing solutions that consider the needs of people with disabilities can promote better products for users of all abilities [167].

5.4 Future Directions for Accessibility Research

Although substantial research and technology is moving from the design of interfaces between people and machines toward the design of "interspaces" occupied by "multiple people, workstations, and other devices" [14, 245], does this approach account for permanently impaired users?

A better understanding of representative users, their capabilities, and their pressing needs and challenges can expedite the development of accessibility from both research and technological outlooks. This will subsequently facilitate better interpretation of research results and applications of these results to a broader range of users, and will further enhance the accessibility of technology used.

Furthermore, it is important to acknowledge that participating in studies and completing study tasks might cause fatigue on users of all abilities, with a stronger effect on users with permanent impairments [189]. Therefore, it is important to build such modeling techniques that are able to gather users' functional and individualistic capabilities based on a limited number of observations [61]. Moreover, scholars widely suggest that accessible interaction would benefit from being accompanied by sophisticated personalization infrastructure, adaptive algorithms, and interaction techniques with regard to mutually dependent user demands and technology capabilities [134]. According to Froehlich et al. [59], modeling accessibility is a complex challenge that requires understanding of different aspects including users and their abilities and needs. For example, a motor-impaired user cannot efficiently use standard multidimensional input devices, such as a keyboard and/or mouse [223]. Similarly, text entry imposes several challenges on users with permanent motor impairments when using both stationary (e.g., desktop computers) and mobile technology (e.g., smartphones) [247]. Motor-impaired users require physical stability, tactility, accuracy, and control to accomplish successful text entry [247]. Modeling also requires assessment and prioritization of accessibility barriers as well understanding of users' varying needs (e.g., due to fatigue) [59].

Furthermore, research has shown that permanently impaired users would like to share their knowledge and skills, such as medical experience, traveling tips, organizational skills, and ICT literacy. Hence, Liu et al. [133] argue that when designing for people with disabilities, the technology should be able to leverage their strengths and capabilities. The importance of focusing on abilities of people rather than disabilities when designing accessible technology has been a hot topic for a decade [252].

As interfaces become more sophisticated, it is more likely that the number of configuration options will increase rapidly. Individualistic characteristics of users vary significantly for different reasons, including, but not limited to, user health conditions and environmental factors [189]. Therefore, it is argued that meeting all users' needs with a single interface is not possible [23]. Hence, when talking about accessibility, it is important to remember that there is no one-size-fits-all approach [9]. Therefore, it is important to account for personalization when creating accessible technology so that a user's unique needs and abilities are assessed with the further translation into personalized design adaptations [61]. Furthermore, within each modality, there is always a range of abilities that might also be transitory in nature [9]. Carter et al. [28] argue that for the the interface to be accessible, two requirements should be met: (1) the user must be able to navigate to any of the interactors of the interface, and (2) the user must be able to control the chosen interactor. Therefore, to be efficient, adaptive interfaces should ideally be adaptive in their nature to reflect the change in abilities and user needs [61].

However, there are also several directions for research to be explored to progress accessibility research further, including the trade-off of the personalized adaptation taking place in the choice of keeping the familiar interface for the user or providing the user with the suboptimal adaptation [61]. Accessibility research suggests adapting interfaces to the user's individualistic needs as a major solution to enhance accessibility of technology [251]. However, there are many unknowns underlying in this solution. For example, the impact of changes in psychological and emotional conditions on adaptive interfaces remains unclear, and therefore these aspects need future investigation.

In addition, it has been stated numerous times in the literature that design solutions successful in one domain can also be successful in another domain [247]. This statement holds true in both directions, as badly designed interfaces are difficult to use not only by permanently impaired users but also by everyone—"they handicap all users" [6, 228]. Moreover, designing assistive and accessible technology might have an influence not only on impaired users but also the human assistance they require: rather than replacing human assistance, technology can potentially change the human assistance needed [131].

Finally, it is also important to include accessibility in university curricula to build the community of accessibility scholars and designers. For example, Putnam et al. [191] argue that a better understanding of how academic professionals consider and receive accessibility has an important influence on academic programs in HCI and UX as well as preparing future advocates for inclusive design. In other words, studying accessibility can direct the HCI community's focus on the most impactful problems, define new directions to support critical thinking about the research, and identify new ways for interdisciplinary collaboration [142].

5.5 Limitations

Our survey has several limitations. First, it is strictly limited to the results of our search. Although we tried to have the most extensive search possible, it is possible that some papers were not included in our sample due to the usage of other keywords we did not consider or were published in venues outside computer science (e.g., publications in medicine-related venues). Furthermore, we did not consider publications that did not report on user studies. This, however, was by design, as we wanted to focus on methodological standards in motor impairments research. Moreover, we did not provide an overview of technological solutions that exist in the literature to assist motor-impaired users. This was outside the scope of our survey, as we focused on methodological aspects of conducting research with motor-impaired participants. Finally, in our survey, we focused strictly on motor impairments; however, it is necessary to conduct similar surveys on other types of impairments to obtain a holistic view of methodological standards in accessibility research.

6 CONCLUSION

In this survey, we systematically reviewed methodological approaches in conducting accessibility research for motor impairments. Through an analysis of 177 papers reporting 228 user studies in the domain, we identified the change and trends in technology used in user studies in the field over the past two decades. Furthermore, we assessed user representation in the studies and provided an overview of standards used to measure functional capabilities of motor-impaired users. Finally, we discussed existing challenges and defined future directions for accessibility research and contributed toward advancement of accessibility research in creating technology for motor-impaired users.

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