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Identification of Challenges and Best Practices for Including Users with Disabilities in User-Based Testing

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Abstract: Despite efforts to promote digital inclusion for all, individuals with disabilities continue to experience a significant digital divide. Developing usable and accessible solutions also demands conducting user-based testing with real end users, particularly for users with disabilities, to detect and address real problems and barriers they experience and improve usability and accessibility based on their feedback through a user-centered approach. When including users with disabilities in user testing, additional attention must be paid to ensure that the testing is planned and carried out in such a way as to enable the successful and efficient integration of users with disabilities. In doing so, it is necessary to consider various restrictions related to users' disabilities. By conducting a systematic literature review, we collected and analyzed the challenges of including users with disabilities in user-based testing and best practices that researchers can apply in future user-based testing with users with disabilities. In the existing literature, a positive trend toward publishing articles describing testing with users with disabilities is noticeable. There is also an apparent need for more reporting on some phases of the testing studies. The main result of this study is a list of challenges and best practices that are important in the different phases of user-based testing with users with disabilities.

Keywords: UX evaluation; inclusive UX evaluation; inclusion of persons with disabilities; accessibility

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1. Introduction

Disability is an umbrella term for impairments, activity limitations, and participation restrictions. It denotes the negative aspects of the interaction between a person's health condition(s) and that individual's environmental and personal factors [1]. Persons with disabilities include those who have long-term physical, mental, intellectual, or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others [2].

According to the World Health Organization's estimation, 1.3 billion people, representing 16% of the global population, experience a significant disability. The number is growing because of increased noncommunicable diseases and people living longer [3]. Mobility disability, the most common disability, affects 1 in 7 adults [4]. In 2019, it was estimated that 970 million people were living with a mental disorder [5]. Vision impairment affects the quality of life of nearly 2.2 billion people, who often have lower workforce participation and productivity rates and higher rates of depression and anxiety [6,7]. By 2050, nearly 2.5 billion people will have some degree of hearing loss, and at least 700 million will require hearing rehabilitation [8].

Different impairments affect many aspects of a person's life including communication and speech, cognition, education, employment, etc. For example, persons with brain injury,

locked-in syndrome, cerebral palsy, muscular dystrophy, or amyotrophic lateral sclerosis may have limited limb movement ability [9]. People with neuromuscular problems usually lose a degree of autonomy in their daily activities [10]. People with severe disabilities such as amyotrophic lateral sclerosis, motor neuron diseases, cerebral palsy, stroke, and spinal cord injury with intubation have different degrees of communication problems [11]. With ageing, disability becomes more common, affecting around two in five adults aged 65 and older. The number of older people prone to various diseases that impact their effective use of information communication technologies (ICT) is expected to double by 2050 [12].

Disability has started to gain momentum as a priority issue in international cooperation for inclusive development [13]. In the 2030 Agenda, disability is recognized as a cross-cutting issue and addressed in the following Sustainable Development Goals [14]: Goal 4—Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all; Goal 8—Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all; Goal 10—Reduce inequality within and among countries; Goal 11—Make cities and human settlements inclusive, safe, resilient, and sustainable; and Goal 17—Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development.

Although there is a tremendous effort in enabling digital inclusion to ensure that every individual has access to information and communication technologies (ICT), people with disabilities are still facing a significant digital divide [15]. Inclusive design is essential to creating products that target a diverse audience. User Interface (UI) designers face different challenges while designing UIs for interactive systems due to the heterogeneity, which can also result from a diversity of end users and interaction modalities [16]. Designers and developers of adaptive applications with UIs able to adapt interaction contents and information processing modes according to users' needs and disabilities especially face significant difficulties in implementing such applications that meet the dynamic of their environment [17].

The successful development of usable and accessible solutions demands the design and conducting of usability studies. Usability evaluation can ensure that interactive systems (i.e., software, a website, or any information and communication technology or service) are adapted to the users and their tasks and that there are no adverse outcomes of their usage [18]. In user-based testing, it is very important to include real end users because only with their feedback can the development process result in applications that best serve the interests of end users. Evaluation by real users is the most valuable technique because it enables the detection of real problems and barriers that users experience while using the solution [19].

In general, when designing and conducting usability testing, it is recommended to follow principles and guidelines provided by existing standards. For applying interaction principles and the general design recommendations for interactive systems, ISO 9241-110:2020 [20] can be followed. A classification of evaluation techniques and guidelines for preparing an evaluation report based on a common industry format and the selected evaluation approach(es) are provided by ISO/IEC 25066:2016 [21]. The standard ISO 9241-210:2019 [22] provides requirements and recommendations for HCD principles and activities throughout the life cycle of computer-based interactive systems.

In the existing literature, researchers often report practical experiences and some general guidelines on conducting user-based testing. However, guidelines or recommendations for successful user-based testing with users with disabilities are missing in the existing literature. Therefore, user-based testing with users with disabilities calls for research and activities that will establish appropriate frameworks and guidelines for the effective inclusion of such users as well as equal opportunities for users with different types of disabilities. To the best of our knowledge, this study is the first attempt at (1) the identification of the most common barriers when including users with disabilities in user-based testing and (2) the identification of good practices that need to be followed in the design and execution of user-based testing that involves users with disabilities. The main contribution of this study

is a list of challenges and best practices for involving users with disabilities in user-based testing that have been documented in existing scientific literature. The result of our research can be used to identify shortcomings in the existing literature in this field. The results of this study also provide the basis for building a catalogue of patterns of adequate inclusion of users with barriers in user testing.

2. Backgrounds

2.1. Human-Centered Design (HCD) for Usable and Accessible Solutions

The effective way to achieve high usability in modern solutions is to incorporate human-centered design (HCD) into the development process [23]. HCD "is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance." [22] In the HCD process, we should follow the following principles specified by ISO 9241-210 [22,24]: (1) understand the user, the task and environmental requirements; (2) encourage the early and active involvement of users; (3) be driven and refined by user-centered evaluation; (4) include iteration of design solutions; (5) address the whole user experience; (6) encourage multi-disciplinary design.

Usability, accessibility, user experience (UX), and HCD have become essential issues to guarantee the quality and success of a software project [25]. When developing solutions tailored to the needs of users with disabilities, the user-centered approach allows understanding the experiences of such users, and based on the results, the usability, UX, and accessibility of these can be improved [26]. Usability is defined by the ISO 9241-11 ergonomics of human–system interaction—Part 11: Usability: Definitions and concepts as [27] "extent to which specified users can use a system, product or service to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". UX, on the other hand, is defined as "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service. Users' perceptions and responses include the users' emotions, beliefs, preferences, perceptions, comfort, behaviours, and accomplishments that occur before, during and after use." [22] Accessibility is defined as "extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals in identified contexts of use" [27].

2.2. User-Based Testing with Users with Disabilities

One of the most widely used methods that involves end users is usability testing, also called user-based testing, in which users perform real tasks with a prototype or real system [23], usually using one or more specific UIs. In the iterative user-centered design process, end-user participation is essential for applying techniques such as observation of users, performance-related measurements, questionnaires, interviews, and thinking aloud [28]. Especially when targeting users with disabilities, when it comes to user-based testing, it is essential to involve such users in the process to ensure that the product is usable and accessible to everyone. Usability assessment has been recognized as a critical success factor in developing usable interactive systems with increased productivity, reduced errors, reduced need for user training and user support, and improved acceptance by their users [29].

User-based testing with users with disabilities is paramount for investigating interaction and other difficulties with the product and enhancing the accessibility of a product [30]. Moreover, the expertise of each user, the configuration of the system, and the assistive products [31] utilized by the user are just a few of the variables that can determine whether the user manages to overcome a potential barrier or not [19]. Users can also be asked to explore the product freely while their behaviors are observed and recorded to identify

design flaws that cause user errors or difficulties [18]. During the session, a researcher or more researchers observe the participant's behavior and listen for feedback, enabling different variables to be measured (e.g., task completion time, the accuracy of execution, navigation behavior, etc.). Based on the qualitative and quantitative data analysis, the product's usability can be improved. The participatory assessment methods with real end users who employ a UI as they work through task scenarios and give feedback provide better insight into the underlying causes of system usability problems users encounter [29].

When user-based testing aims to assess the solution's performance in terms of the speed of performing tasks or errors when using the solution, it does not matter which users we include. Existing research has shown that performance of users with disabilities while testing a product can be very close to the performance of users without disabilities [26,32,33]. However, when analyzing and comparing the benefits of products for users with disabilities, the results between users with disabilities and users without disabilities can differ significantly. The difference could be attributed to the greater utilization of new technology's advantages to people with disabilities, while those without disabilities take less advantage of the benefits or do not even need them as much. For example, the study by Giudice et al. demonstrated that older adults who are blind or have a visual disability and experience difficulties in navigating could significantly benefit from a navigation system, and evaluating older participants with a visual disability is important, as the majority of vision loss is related to age [32].

3. Materials and Methods

We conducted a systematic literature review (SLR) to identify state-of-the-art research in the field of end-user testing with users with disabilities and to observe trends in research. We followed the guidelines prepared by Kitchenham [34] (see Figure 1).

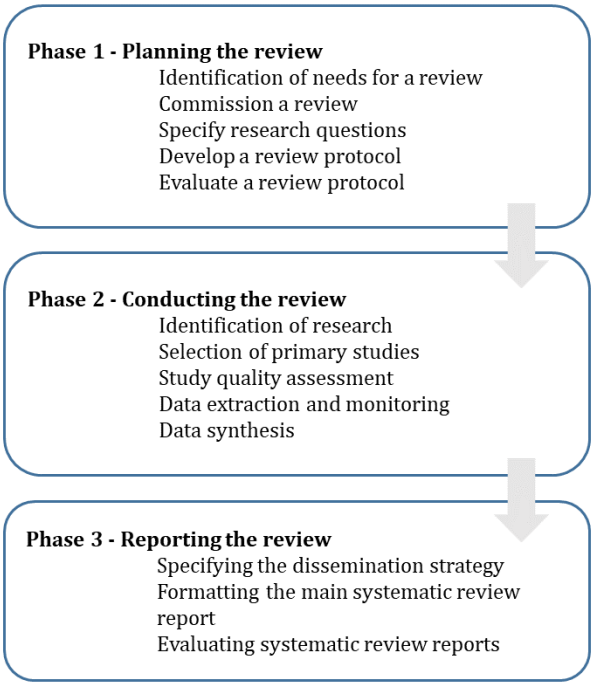


Figure 1. Systematic literature review process adapted from [34].

Five researchers were involved in the SLR process, with research activities divided into five phases, as shown in Figure 2. In Phase 1, the researchers jointly defined and agreed on defined research questions (see Table 1), and developed the review protocol. In the review protocol, the researchers specified the query string for searching the relevant literature (see Section 3.2) in selected data libraries (see selected libraries in Table 2). The researchers jointly defined and agreed on defined criteria based on which we decided to

include or exclude the found article for further reading (see Table 3 for inclusion criteria and Table 4 for exclusion criteria). Additionally, in the research protocol, the researchers agreed on four quality criteria (see Table 5 for quality criteria) for selecting articles with quality written content enabling data extraction based on this study's objectives. The researchers jointly specified data fields and developed a data extraction form in the online tool for the SLR process.

In Phase 2, articles were identified based on a research string in online databases, and primary studies were selected for further analysis using the stepwise approach defined in the selection process (see Section 3.2). The selection of primary studies was first filtered with screening of the papers by reading the title and the abstract. All articles selected for further reading based on the inclusion criteria were additionally evaluated with quality criteria jointly defined and confirmed by the researchers.

In Phase 3, the researchers read the selected articles and extracted data from primary studies using the designed data extraction forms (see Section 3.3). Each researcher reviewed their part of the articles, whereby the number of articles was divided equally among all researchers. In Phase 4, the extracted data were analyzed and interpreted according to the research questions. The research protocol was concluded in Phase 5 with writing activities.

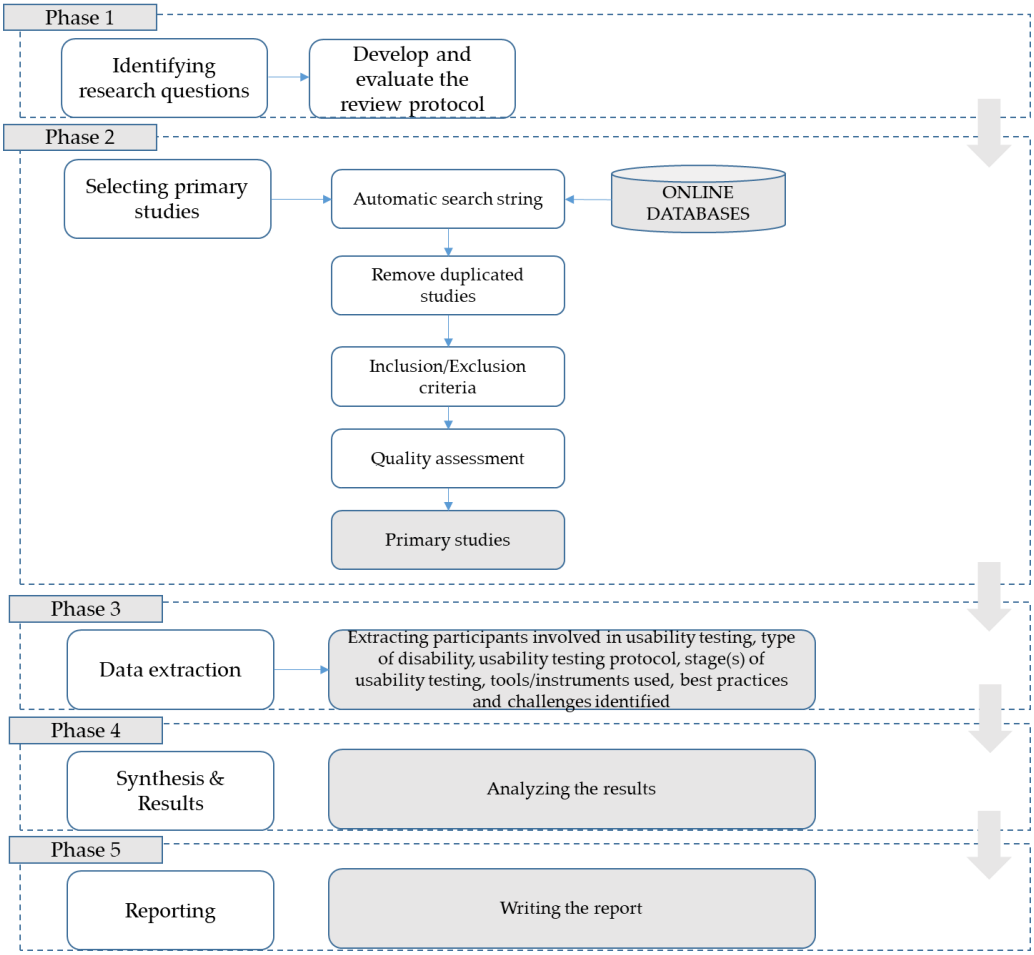


Figure 2. Research process map.

Table 1. Research questions.

	Research Question
RQ1	What have been the trends and demographics of the literature within the field of user testing with users with disabilities?
RQ2	What barriers do researchers encounter in user testing where users with disabilities are included?
RQ3	Based on existing research and experience, what good practices should be followed for the successful inclusion of users with disabilities in different phases of user-based testing?

Table 2. Articles retrieved from the selected digital libraries using the specified search string.

Database	URL	Nr. of Articles
ACM Digital Library	https://dl.acm.org/	562
IEEE Xplore	https://ieeexplore.ieee.org/	152
Scopus	https://www.scopus.com/	255
Web of Science	https://www.webofscience.com/	116
Together		1085

Table 3. Inclusion criteria.

	Criteria	Description
I1	Field	Include articles that provide information about user-based testing.
I2	Language	Include articles that are written in English.
I3	Availability	Include articles that are accessible electronically.
I4	Literature type	Include articles published in peer-reviewed journals, conference proceedings, or a book (e.g., lecture notes).

Table 4. Exclusion criteria.

	Criteria	Description
E1	Year	Exclude literature published before the Year 2012.
E2	Duplicates	Exclude any duplicated studies found in multiple databases.
E3	Research area	Exclude non-computer science or non-HCI literature.
E4	Methodology type	Exclude non-original research or articles that report the results of a systematic literature review or systematic mapping study.
E5	Abstract only	Exclude extended abstracts or posters

The reliability and quality of the SLR process were provided with the help of cross-checking in different phases. In Phase 2, each researcher evaluated two random papers, also assigned to other researchers, with altogether eight papers per researcher, and cross-checked if the quality criteria were correctly applied. In Phase 3, the cross-checking activity was repeated, and each researcher evaluated one random paper, assigned to other researchers, and cross-checked if the quality of extracted data was reasonable. Access to the results of all researchers was possible through a web tool used for the literature review process. The online tool for conducting a systematic literature review used in this study was Parsifal [35], designed to support researchers in performing systematic literature reviews within the context of software engineering. The Parsifal tool enables geographically distributed researchers to collaborate by providing a shared workspace, designing the protocol, and conducting the research. This tool provided us with a shared repository of all selected articles and access to all data throughout the systematic literature review process. Since no issues were identified during cross-checking, all researchers were well coordinated in understanding the defined procedures in the protocol and shared the same view on the content and quality of the data.

Table 5. Quality criteria.

	Criteria	Description	Answer [Weight]
Q1	Writing quality	Articles containing well-written essential elements such as an abstract, introduction, materials and methods, discussion, and conclusions from which it is possible to understand the data that interested us in our research effectively.	High [10]; Medium [5]; Low [0]
Q2	Venue quality	The article is published in a journal, or in the conference proceeding.	High [10]; Medium [5]; Low [0]
Q3	User testing description	The description of the testing process contained detailed and comprehensively described procedures of individual testing phases such as preparation of tasks, recruitment, execution of the test, etc.	High [10]; Medium [5]; Low [0]
Q4	Users with disabilities are included	Persons with disabilities are included in the user testing.	Yes [10]; No [0]

3.1. Phase 1: Definition of Research Questions and Review Protocol

The primary goal of this study is to identify, analyze, and synthesize existing work in the usability testing field. The main objective of this study is to (1) systematically review relevant scientific articles to conduct a SLR of the user-centered testing with users with disabilities field and to (2) present trends and demographic analysis of the research field. Based on the research goal, we formulated three main research questions RQ1, RQ2, and RQ3, as presented in Table 1.

3.2. Phase 2: Selecting the Primary Research

After identifying the research questions, we defined the appropriate keywords for finding all published articles with topics from user-centered testing with users with disabilities fields. As we wanted to provide a comprehensive overview of the research area, broad keywords were used. The elementary search query string used for finding published articles was the following:

(“user test*” OR “user evaluation”) AND (“UX” OR “user experience” OR “accessibility” OR “accessible” OR “barriers” OR “diversity” OR “usability”) AND (“disab*” OR “Down’s syndrome” OR “hard of hearing” OR “intellectual disability” OR “low dexterity” OR “low vision” OR “ASD” OR “autis*” OR “blind*” OR “deaf*” OR “dyslex*” OR “hemiplegia” OR “impairment” OR “paraplegia” OR “wheelchair”).

To find the relevant literature, we used the following established publicly available digital libraries: ACM Digital Library, IEEE Xplore, Scopus, and Web of Science. The first search conducted using the digital libraries yielded 1085 articles. The number of articles retrieved from selected digital libraries that were used as input into the next selection process steps is presented in Table 2. The most considerable number of articles was found in ACM Digital Library (562), followed by Scopus (255), IEEE Xplore (152), and Web of Science (116). To include relevant articles and exclude irrelevant ones, several inclusion (see the criteria specification in Table 3) and exclusion criteria (see Table 4) were applied. The last step in the selection process was to assess the quality of articles with the defined criteria (see Table 5). The article evaluated with at least 25 scores was selected as primary research and included in the future analysis.

We have followed several criteria for selecting studies for data extraction as follows (see Table 3). Since this study aimed to review challenges and best practices in user-based testing with users with disabilities, only articles that reported user-based testing of a product or service were included (I1). We searched for this information in the title, abstract, and full text. Since this review involved an international team of researchers,

the inclusion criteria (I2) (the language) was set to prevent errors in data selection and extraction in case articles written in non-English language could prevent cross-checking and comparison between individual researchers. The inclusion criteria (I3) was set to include only articles accessible and downloadable in full-length through digital libraries. Final inclusion criteria (I4) was set for selecting articles published in journals that usually comprehensively describe studies performed. Although conference papers may be shorter and often only provide some information in detail compared to journal papers, there is a possibility of also finding quality papers published in conference proceedings. Therefore, at this stage, we decided to also include articles published in conference proceedings. However, before selected papers were finally reviewed for data extraction, they were assessed with the defined quality criteria (see Table 5).

We have also followed several criteria (see Table 4) for excluding identified studies from data extraction as follows. With the exclusion criteria E1, the research team decided to restrict the research to the last ten years (2012–2022). The main reason for that decision was to obtain a balanced inclusion of different types of disability. For instance, cognitive accessibility is an issue that only started to appear in research in the last few years. Next, because the same article can be indexed in different databases, and the search in different digital libraries often provides links to the same article, the results of the search were checked for duplicates, which were removed from the final list of selected articles (E2). In this study, we were interested in user-based testing, specifically in computer-based HCI. Therefore, all articles reporting studies of non-computer-related HCI were excluded (E3). The research team also agreed to exclude non-original articles that reported results from existing literature reviews or systematic mapping studies (E4). Finally, to be able to extract all data as specified in Section 3.3, studies for which only abstracts were accessible (E5) were excluded from the final list.

In the literature review, we searched for peer-reviewed articles published in journals and proceedings of international conferences. Such publications are expected to have gone through review procedures. However, we still wanted to carry out an additional analysis of the writing quality (Q1) of the articles found. We evaluated the identified articles according to the quality of the writing, checking whether the articles contained well-written essential elements such as an abstract, introduction, materials and methods, discussion, and conclusions from which it is possible to understand the data that interested us in our research effectively. Each article was also assessed based on the quality of the venue (Q2), wherein we checked whether the article was published in a journal with the impact factor as to whether it was in a conference proceeding. Venue quality was mainly based on inclusion in the Journal Citation Reports (for Journals), or the CORE ranking (for conferences). In each article we evaluated, we looked for whether the testing procedures were described and what the quality of the procedure description was. We were interested in whether the description process described different phases such as preparation of tasks, recruitment, execution of the test, etc. (Q3). Since our research aimed to gather barriers and good practices in the inclusion of users with disabilities, the article needed to report the implementation of a study with the inclusion of such users (Q4). We were interested in those studies that, based on practical experience, could provide the challenges in including users with disabilities in the user-based testing and good practices based on practical experience.

The process of selecting the relevant literature was carried out in several steps (see Figure 3 and Table 6). In the second step, we limited the set of studies by applying the exclusion criteria E1 to include only studies published in 2012 or later, which resulted in a set of 852 studies. In the next step, removing 34 duplicate entries resulted in 818 articles used for the next step of the selection process. In the fourth step, the exclusion criteria (I1–I4 and E3–E5) were applied to exclude irrelevant studies. Based on titles, reading abstracts, and conclusion, the studies that address user testing of a product or service with people with disabilities were selected. Although the language criteria were applied already in the previous step, some articles we found had titles and abstracts in written English. However, the rest of the article was not written in English. Therefore, this step provided 134 articles

published in a journal, conference proceeding, or a book section. The selection process was concluded with a quality assessment. Based on quality criteria, 84 articles were relevant and marked as primary research. The list of primary studies S1–S84 identified in the literature review is provided in Table A1 in Appendix A.

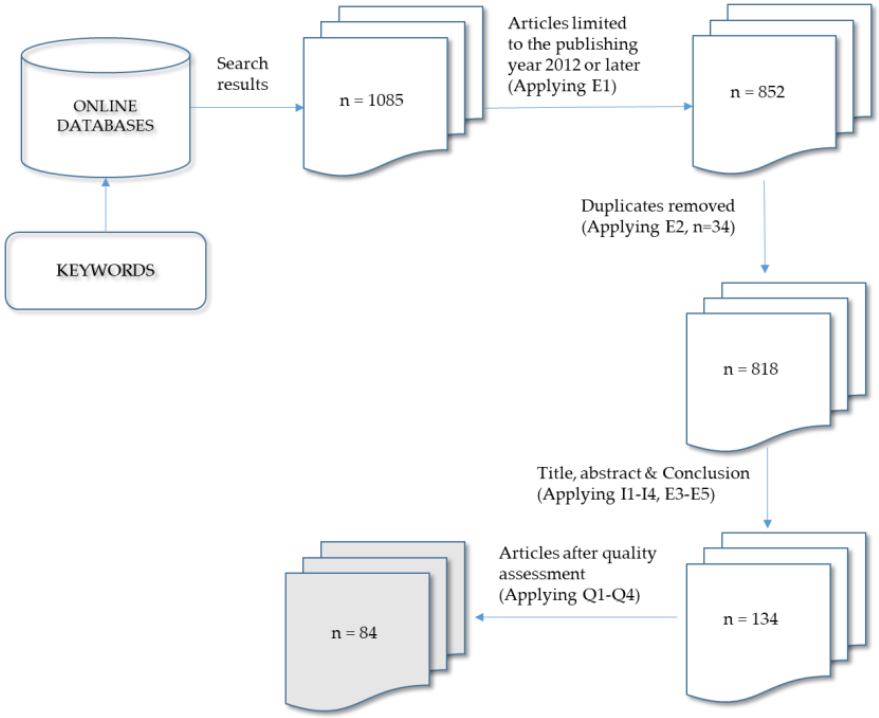


Figure 3. Flow diagram of the database searches and article screenings process.

Table 6. Steps in screening and selection of the relevant literature.

Step	Activity	Nr. of Articles
I	Automatic search in digital libraries	1085
II	Applying E1	852
III	Applying E6 (removing the duplicates)	818
IV	Screening by title and reading abstract and conclusion (applying I1–I4, E3–E7)	134
V	Quality assessment	84

3.3. Phase 3: Data Extraction

To ensure that all primary studies would be analyzed consistently, a data extraction form was designed to record the information obtained from the primary studies accurately. In addition, the extraction form was used to ensure the quality collection of all information needed to address the review question. As presented in Table 7, the data collection form was divided into two sections. Section A provides the extraction of standard information of primary research, while Section B addresses the content data. Aggregation of data extraction from all primary studies provided relevant results for further analysis. The main results are presented in the following section.

Table 7. Data collection form.

	Description	Type	Value
Section A			
EA1	Data Extractor	String field	n/a
EA2	Study Identifier	Integer field	S [1–n]
EA3	Name of database	String field	n/a
EA4	Title of primary research	String field	n/a
EA5	Author	String field	n/a
EA6	Year	Integer field	[2012–2022]
EA7	Publication type	String field	[book chapter/journal paper/conference proceeding]
EA8	Journal	String field	n/a
EA9	Pages	Integer field	n/a
EA10	Volume	Integer field	n/a
EA11	doi	Integer field	n/a
Section B			
EB1	Type of disability	Multiple choice	1. Not specified 2. Blind 3. Low vision 4. Deaf 5. Hard of hearing 6. Low dexterity 7. Wheelchair user 8. Hemiplegia 9. Paraplegia 10. Quadriplegia 11. Intellectual disability 12. Dyslexia 13. ASD (autism) 14. Down's syndrome 15. Other
EB2	Stage(s) of usability testing described 1. Preparation of tasks 2. Prototype preparation 3. Ethical issues 4. Recruitment 5. Welcome 6. Pre-test questionnaires 7. Test execution 8. Post-test questionnaires 9. Post-evaluation feedback.	String field String field String field String field String field String field String field String field String field	n/a n/a n/a n/a n/a n/a n/a n/a n/a
EB3	Number of users involved	Integer field	[0–n]
EB4	Tools/instruments used	String field	n/a
EB5	Best practices identified	String field	n/a
EB6	Challenges identified	String field	n/a

4. Results

4.1. Trends and Demographics of the Literature within the Field

As illustrated in Figure 4, the number of published studies has been increasing in the last decade. A clear trend in increased interest in the observed field can be reported. Along with the increasing number of primary studies in recent years, we also noticed the change in the article types: a positive trend in the number of journal papers compared to other primary research types can be observed since 2016.

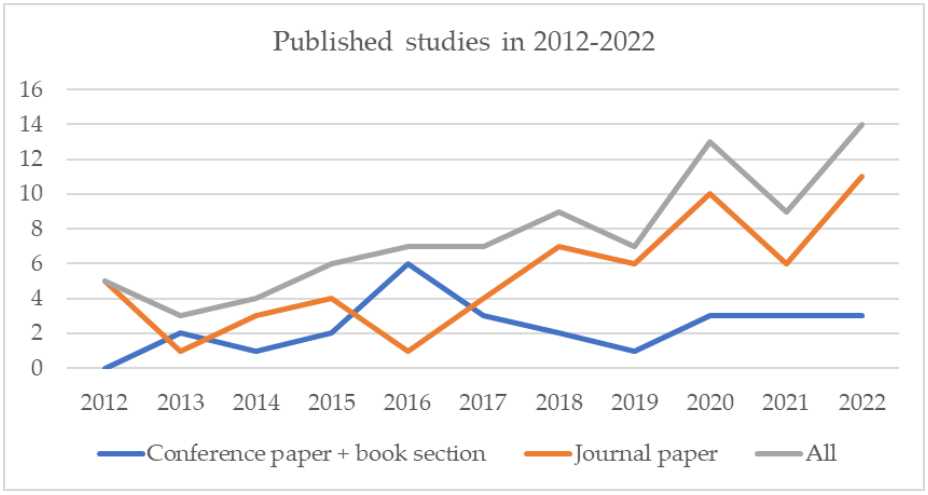


Figure 4. Number of studies published from 2012 to 2022.

As shown in Figure 5, most (69%) papers reporting user-based testing studies involving users with disabilities have been published in journals. A total of 21% of articles were published in conference proceedings, and 10% of studies were published in books as a chapter.

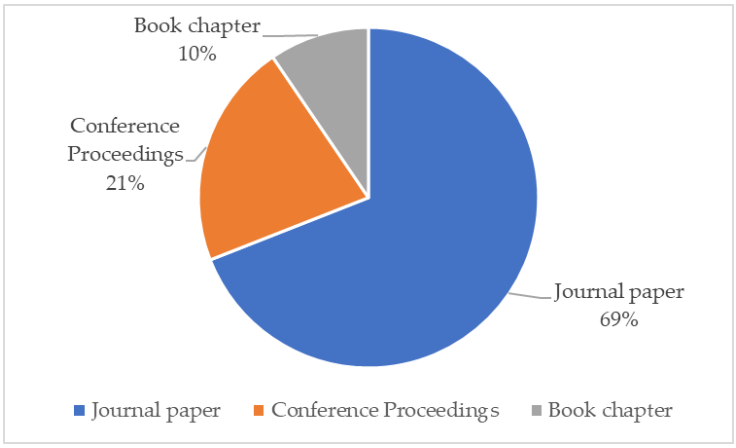


Figure 5. Percentage of papers based on publication type (All = 84).

We ranked the journals and conferences by the number of primary articles published to obtain a broader view of top venues for the literature reporting results of the user-based testing that included users with disabilities. Results presented in Table 8 indicate that research articles could be found in a broad spectrum of journals. Most primary studies have been published in Universal Access in the Information Society (8), ACM Transactions on Accessible Computing (7), Assistive Technology (4), and Disability and Rehabilitation: Assistive Technology Frontiers in Neuroscience (4). Seven papers presented at different conferences were published as a chapter in Lecture Notes in Computer Science. The conferences with the most published studies about user-based testing with users with disabilities are International Web for All Conference, Iberian Conference on Information Systems and Technologies (CISTI), International ACM SIGACCESS Conference on Computers and Accessibility, and CHI Conference on Human Factors in Computing Systems.

Table 8. Top journals and conferences regarding the number of published articles.

Journal	Nr. of Articles
Universal Access in the Information Society	8
ACM Transactions on Accessible Computing	7
Assistive Technology	4
Disability and Rehabilitation: Assistive Technology	4
Frontiers in Neuroscience	2
Procedia Computer Science	2
Book chapters and conference proceedings	**Nr. of Articles**
Lecture Notes in Computer Science	8
International Web for All Conference	2
Iberian Conference on Information Systems and Technologies (CISTI)	2
International ACM SIGACCESS Conference on Computers and Accessibility	2
CHI Conference on Human Factors in Computing Systems	2
Annual ACM Symposium on User Interface Software and Technology	1
Annual ACM Symposium on Applied Computing	1
International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-exclusion	1

4.2. The Research Space of the Literature within the Field of User-Based Testing with Users with Disabilities

In the existing literature related to testing users with disabilities, we see that some groups of users with disabilities are much better represented than others (see Table 9). Most often, blind users were included in user testing (they appeared in 40 studies) and visually impaired users (we counted 33 occurrences). Users with intellectual disabilities (N = 12), deaf users (N = 7), and users with hearing disabilities (N = 5) were also frequently included. Additionally, in the existing literature, some studies had users with mobility impairments, namely wheelchair users (N = 7), users with quadriplegia (N = 5), users with hemiplegia (N = 5), and users with paraplegia (N = 3). Few studies included users with autism (N = 3), users with dyslexia (N = 1), and users with Down's syndrome (N = 1). In 30 cases, we classified the type of disability with "others" according to the classification schema specified in the data extraction form. We did not find a study where it was not possible to define the type of disability of the users who were involved in user-based testing.

Table 9. Involvement of users in existing user-based testing research according to the type of disability (in a descending order).

Disability Type	N of Occurrences
Blind	40
Low vision	33
Other	30
Intellectual disability	12
Deaf	7
Wheelchair user	7
Hard of hearing	5
Low dexterity	5
Quadriplegia	5
Hemiplegia	4
Paraplegia	3
ASD (autism)	3
Dyslexia	1
Down's syndrome	1
Not specified	0

From more than half of the analyzed articles, we were able to extract information about the following activities: preparation of the prototype (41 articles reported this activity),

the recruitment of users with disabilities (extracted from 51 articles), the implementation of testing (extracted from 61) and the implementation of post-test questionnaires (there were 51 articles providing the description) (see Figure 6). More than 30 articles described the preparation of test tasks and pre-test and post-evaluation questionnaires. Other activities (e.g., obtaining the consent of the ethics committee and welcoming) are rarely described in the articles. Considering that users with disabilities are invited to participate in these studies, we expect to see more papers reporting how ethics committee approvals were obtained.

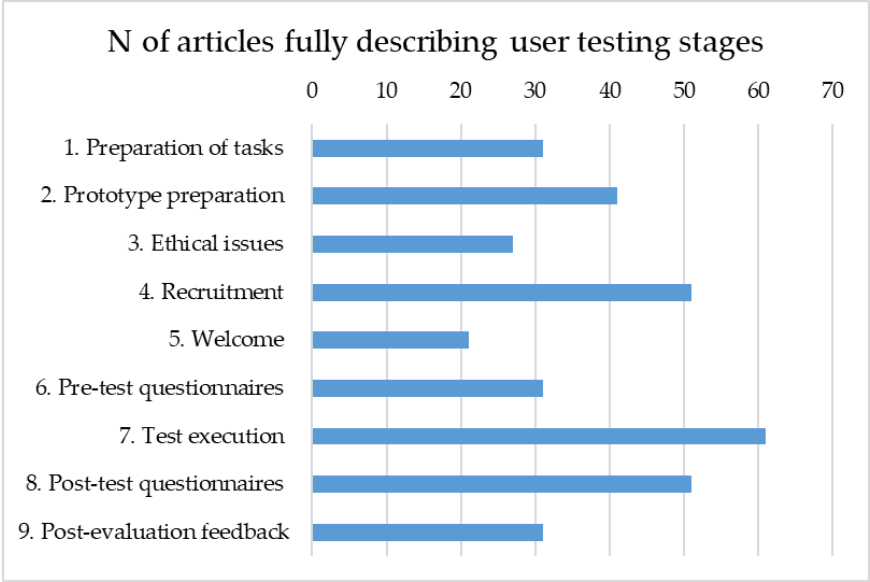


Figure 6. Number of articles with descriptions of individual testing stages.

Regarding the number of users involved in the testing, in existing user-based testing research, most often (N = 24), between 6 and 10 users with disabilities are involved in such studies (see Figure 7). Existing user testing studies generally involve a small number of users with disabilities (on average, 17). In 9 studies, up to 5 users with disabilities were included. A number between 11 and 15 users with disabilities participated was counted in 16 existing user-based testing studies. Between 16 and 20 disabled users participated in 8 such studies. There were 5 studies that included between 21 and 25 users with disabilities. We also found 6 studies where more than 40 users with disabilities were included, and in 6 cases, the number of users with disabilities participating was not reported.

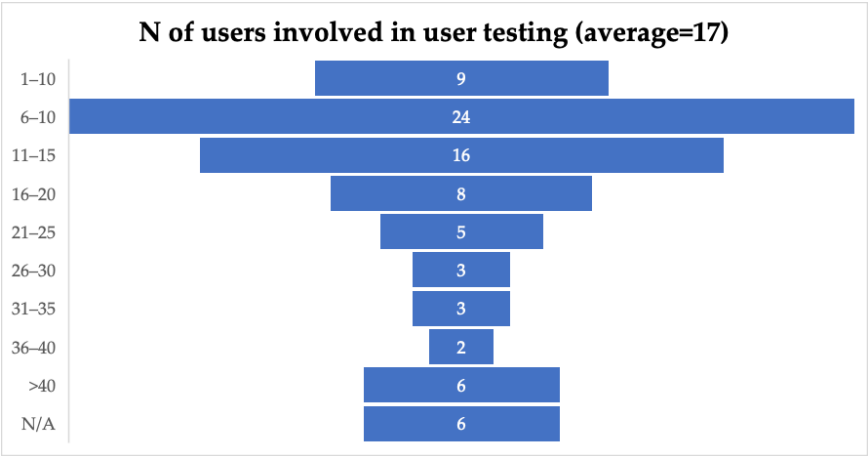


Figure 7. Number of users involved in existing user-based research.

4.3. The Challenges of Including Users with Disabilities in User-Based Testing

In the existing literature, the authors identified numerous challenges in user-based testing in general and especially when the user-based testing included users with disabilities. Among the most documented was the poor experience when performing testing online, which was often the case during the pandemic. The results were unreliable when conducting remote testing, where the users with disabilities commonly reported being confused and not having clear enough instructions as the primary source of the problem. In several cases, the user testing could only be completed with the help of caregivers, especially in instances where children and young adults with communication difficulties were involved. The complexity of tools and problems in setting up the devices to meet individual users' needs were also reported, mainly in cases of people with visual impairment and people with postural issues including older adults who could not finish long-seated sessions. Cultural differences were also addressed in user-based testing cases with people with or without disabilities, and lastly, no compensation to users was noted as a more considerable barrier. All identified literature review challenges are reported and explained in the following table (see Table 10).

Table 10. Challenges of including users with disabilities in user-based testing.

ID	Challenge	Short Explanation
C1. Challenges before user testing		
C1.1	Selecting participants without bias	A common type of bias in participant selection is sampling bias. Bias in participant selection can lead to testing results that do not accurately represent the needs and preferences of the targeted user group. Selecting participants with prior interest or knowledge about the tested solution can also impact user testing results [36].
C1.2	Understanding participants characteristics, needs, and cultural and personal differences	Planning user-based testing, especially with users with disabilities, can be challenged by a poor understanding of cultural and personal differences. Researchers do not understand the specific needs and mindsets of users, both with and without disabilities [37]. Users with disabilities may communicate in different ways or require assistive products. Consequently, the user-based testing processes for users with disabilities are not properly designed and executed. For example, if international user testing participants are included, disregarding cultural differences is problematic [38].
C1.3	Developing protocols for enabling inclusive user-based testing	The design of an inclusive test protocol requires understanding protocol differences for users without disabilities and users with disabilities. Users with disabilities may have different capabilities and limitations, which in turn can affect their ability to participate in tasks that demand physical activity or cognitive load. Due to individual differences in capabilities between different users, results cannot be directly compared [39].
C1.4	Preparing tasks suited to the participants' ability	In user-based testing, where users must complete different tasks, it is essential to prepare tasks that suit users' abilities. For example, participants with intellectual disabilities have difficulties completing complex tasks [40], and for such users preparing tasks aligned with their cognitive effort abilities is critical.
C1.5	Setting up the testing environment according to the specific user needs	The successful implementation of user testing also depends on a properly prepared test environment, which, especially in the case of users with disabilities, must be adapted to the abilities, needs, and other characteristics of the users. Difficulties can occur when setting up the testing environment for each participant with disabilities [41] because different disabilities require different accommodations.
C2. Challenges during user testing		
C2.1	Getting used to and learning how to use the product by the users	The users need help accustoming to the tools or Uis they use for the first time during the testing process [42]. For example, older adults and users with disabilities struggle to use unfamiliar tools [43], which can add additional time and effort to the testing process. This challenge is connected to a variety of factors including the complexity of the UI, the lack of familiarity with the UI, the lack of clear instructions or guidance on how to use the UI effectively, the user's confidence in using the UI, and the time pressure or the need to complete tasks quickly, which can further increase the difficulty of learning and adapting to new tools.

Table 10. *Cont.*

ID	Challenge	Short Explanation
C2.2	Presenting the instructions and tasks to the participants in a clear and accessible way	During testing, the researcher has to provide instructions and task presentations tailored to the specific abilities and limitations of the participants to ensure that the tasks are understandable and accessible to all participants. Participants find it difficult to visualize the problems as they need more real experiences (they cannot judge a game only by watching but must experience playing a game) [44]. Instructions being unclear and confusing [45] can lead to confusion and inaccurate feedback, impacting the validity of testing results.
C2.3	Preventing disruption of the testing process due to malfunctions of the tested product or tools used in the process	While performing user testing, there is a risk of the tested environment malfunctions (freezing, failing to update, etc.) [26]. Any disturbance can affect the length of the testing process and, consequently, the well-being and experience of the participant. Poor accessibility of tools and instruments for measuring or data acquisition during testing procedures can affect the ability to fully capture the feedback of user testing participants with disabilities (e.g., visual disability [46]), resulting in potentially incorrect conclusions. Therefore, various measurement tools used during the testing procedures must also be tested for accessibility, primarily if these tools will be used by the users directly.
C2.4	Including accessible-only products	Products being tested that are not accessible and can be used only by users without disabilities (e.g., without visual disability [47]) lead to incomplete and inaccurate results. Therefore, the test results may not accurately reflect how the product or service will be used and accepted by the different end users.
C2.5	Using assistive technology in a productive manner	Ensuring that the testing environment including all tools used for testing purposes is accessible for participants with different disabilities, the technology is integrated flawlessly into the testing process, preventing any additional barriers for participants with disabilities. For example, the lack of screen reader support on some devices (e.g., smart glasses), a rapidly draining battery used by the device, or dependency on an Internet connection can decrease the success of the testing process. [48]
C2.6	Acquiring unbiased feedback from participants	During the testing procedures, if others are present (e.g., the participant's caregiver or the researcher) in the testing room, the participants often feel obliged to provide only positive feedback. Such impact can make participants' opinions favorable to their caregivers or the researcher [36], leading to biased or incomplete feedback, as participants may be hesitant to provide negative feedback or may not express their true opinions or preferences. In a testing environment setting with observers present during the testing, users tend to increase their emotional control in disadvantageous conditions due to social desirability [49], conforming to the expectations of others rather than their accurate opinions or experiences. This impact can lead to erroneous testing results based on incomplete and dishonest feedback.
C2.7	Preventing the influence of the accompanying person on the course of testing	The behavior or feedback of children and users with disabilities who need caregivers (e.g., young adults with special communication needs [50] who cannot participate in testing alone) might be influenced by the presence of an accompanying person (e.g., parents, caregivers, and others). Sometimes, instead of the user with a disability, the caregiver gives input, leading to testing results that do not reflect the participant's true experiences or feelings.
C2.8	Ensuring efficient online or remote user-based testing for all users	User-based testing in an online environment due to the pandemic or other reasons often results in unreliable findings [51]. Conducting remote user-based testing can bring new challenges, especially when performing research with participants with disabilities when too little support is provided for the users [52]. Participants' technical barriers, such as bad internet connection, device limits, software compatibility issues, and other challenges, can make testing at home only sometimes feasible [53]. In addition to technical issues, there is an issue of environmental control (background noise or poor lighting affecting focus), which can lead to less engaged participants resulting in biased feedback.
C2.9	Organizing on-site testing for participants who have difficulties coming to the laboratory	Some user-based tests require strict laboratory conditions and rigorous protocols that cannot be performed remotely [33]. On-site user-based testing is connected to costs, logistics, scheduling, organizing space and testing equipment, time constraints, recruitment, and other travelling-connected inconveniences, which can discourage users' participation. Therefore, it is necessary to encourage further and enable the conducting of on-site user testing, especially for users with disabilities that otherwise circumstances prevent them or make it harder to come to the laboratory setting.

Table 10. *Cont.*

ID	Challenge	Short Explanation
C2.10	Minimizing the influences of persuasive technologies	Integrating persuasive technologies in the testing environment influences end users' behavior and attitudes [38], potentially affecting participants' decisions and user testing results, not accurately reflecting the true user experience. Researchers need to understand the impact of these technologies on user behavior and attitudes, and it is necessary to implement all measures to reduce the effects.
C2.11	Providing enough time for completing the tasks	Complete novelty, limited experience, or unfamiliarity may impact the results [54], as they affect the time needed to complete the tasks, especially in poor prioritization of testing objectives or unclear time constraints. In the case of including users with disabilities in the testing process, it is necessary to pay special attention to task completion time limits. When the testing process is too complex, with too many steps or variables to consider, subjects can have difficulties performing user testing, requiring more time than expected [55].
C2.12	Providing controlled environment testing conditions comparable to those in the real environment	When conducting user-based testing in a controlled lab setting, the conditions are carefully controlled to eliminate as many external factors as possible that could influence the test results to ensure reliable results. However, such a controlled lab setting may not always reflect the real-world conditions in which users will be using the product, and testing can provide results that significantly differ from those from real-world settings when users perform regular daily activities [54].
C2.13	Ensuring an accessible environment setting during the testing	If the testing environment is not accessible, participants with disabilities can experience difficulties, which will affect testing results. Difficulties in the availability and reliability of the technical infrastructure can create an unsuitable testing environment for an evaluation with users with different disabilities (e.g., visual disability [56]). For example, sitting straight without being able to move the head is potentially challenging for some participants [57]. Next, users with physical disabilities may experience fatigue or discomfort during extended testing sessions, impacting their ability to provide accurate feedback.
C2.14	Efficient management of technical problems during the testing	Solving unexpected technical problems creates time-consuming and challenging activities not directly connected to user testing [58]. Efficient management of the technical difficulties during the testing can be complex because of the time constraints, complexity issues, and unforeseen issues.
C3. Challenges after user testing		
C3.1	Providing adequate compensation for participants	Not compensating users participating in testing creates a bad user experience [59]. However, providing adequate compensation for participants in user-based testing involving users with disabilities can be challenging for several reasons. First, there is always a potential risk of developing a conflict of interest or legal and ethical issues that impacts user testing. Providing compensation for participants with disabilities can raise ethical concerns related to exploitation, coercion, and undue influence. Next, the compensation offered may need to vary depending on the type and severity of the disability and the accommodations required to ensure the participant can effectively participate in testing.
C3.2	Meeting the expectations of participants	Meeting participants' expectations in user-based testing involving users with disabilities can be challenging for several reasons. Participants with disabilities may have diverse needs and expectations regarding testing, making it difficult to anticipate and meet all their needs. Participants with disabilities may experience communication barriers that make it difficult to express their expectations or provide feedback during testing. Unsatisfied expectations can be understood as deception, frustration, or poor user experience [60].

4.4. Best Practices for Successful Inclusion of Users with Disabilities in User Testing

There are many general guidelines available for user testing activities, mostly based on providing accessible material and an accessible testing environment as well as using inclusive and non-offensive language. The systematic literature review resulted in several specific pieces of advice and guidelines on how to implement user testing; some of them were repeated in several articles and are summarized in Table 11. To place them into the three phases of user testing, we classified the identified suggestions in good practices (1) before user testing, (2) during user testing, and (3) after user testing. The largest issue while extracting good practice was to consider the differences in disability types and

consequently the different requirements of each type, making the creation of a list of good practices for everyone or all types of impairments almost impossible.

Table 11. Best practices for inclusion of users with disabilities in user-based testing identified in the literature review.

ID	Best Practice	Short Explanation
BP1. Best practices before user testing		
BP1.1	Explaining user testing goals to participants	Providing information in an accessible format about user testing activities before starting the test will motivate participants to increase their assurance, self-confidence, and self-efficacy [52,56]. Failing to do so, participants will not fully understand what is expected of them or what they can expect from the testing process, endangering the user experience of participants as well as the final results.
BP1.2	Collecting consent from participants	Providing the user's ethical approval and informed consent enables fair, transparent, and accurate research, minimizing harm [59,61]. Participants should also be allowed to withdraw consent during testing, ensuring their privacy will be respected and no adverse consequences can come from testing activities.
BP1.3	Training for participants	Providing the opportunity for training the participants before they start with user testing increases self-confidence, self-efficiency, and motivation, and also reduces stress. [61–63]. This activity ensures participants fully understand how to use the product so they can provide more effective feedback. In some cases, a demonstration of how to use the product or service gives participants a better understanding of how it works and what they need to do during the testing process.
BP1.4	Preparing clear instructions for participants	Providing clear and concise instructions increases the success rate of testing [19]. It ensures participants understand what they need to do during the testing process by using simple language, breaking tasks down into manageable steps, clarifying expectations, and providing examples so that participants can give effective feedback that will improve the tested product.
BP1.5	Using accessibility standards	Ensuring all documents are accessible and standards-compliant to ensure compatibility with assistive products increases testing effectiveness and accessibility for all participants [19]. By following established accessibility guidelines, the involvement of individuals with disabilities is more feasible, ensuring that a wider audience can use the product or service.
BP1.6	Design led by people with disabilities	Moving from design for disabled people to design led by disabled people involves a fundamental shift in the approach to inclusive design and brings people with disabilities into the design process as active and equal partners [64]. Including people with disabilities in user testing ensures that products are accessible and meet the needs of people with disabilities and can lead to more innovative and creative designs that benefit all users, not just those with disabilities.
BP2. Best practices during user testing		
BP2.1	Enabling user testing from home	Allowing participants to perform user testing activities in their homes reduces stress, increases their well-being and relaxation, and avoids costs [33,53]. Remote testing is, however, possible only if instructions are provided clearly, technical support is established, and a variety of communication methods are set to communicate efficiently with the participants during the testing process. A more significant level of flexibility is also required.
BP2.2	Enabling accompanying persons during the testing	Allowing participants to be accompanied by their caregivers, friends, or family members increases their safety, comfort, self-confidence, and self-efficiency [36,40,62,65]. Informing participants of this option, providing them with instructions, and organizing space according to the needs of one additional person increases the chance participants with impairments will participate in testing activities.
BP2.3	Enabling participants to repeat the tasks	The possibility to repeat each task for participants during the user testing activities increases positive user experience and motivation and reduces stress [61]. Connected to providing clear instructions, a more accurate and comprehensive understanding of the user experience can be gained, and new issues can be identified that may have been missed during the initial attempt. Sometimes, using a different approach or method while repeating the tasks (different devices or software) will help identify various issues.

Table 11. *Cont.*

ID	Best Practice	Short Explanation
BP2.4	Providing enough time to complete the tasks	Providing enough time for performing user testing activities allows participants to obtain a good feeling with minimal stress, motivating them and giving them enough time for preparation without rushing to perform the activities [41,66]. Correct estimates of times needed to perform the activities, allowing breaks and flexible schedules ensure that participants can effectively use the product or service being tested and provide comprehensive feedback.
BP2.5	Organizing user testing activities with sufficient breaks	Providing breaks between user testing activities allows a longer concentration of participants [19], ensuring that participants remain engaged and focused throughout the testing session. Schedules should be organized strategically, although flexible according to the user testers' needs, accompanied by refreshments, reducing fatigue, and increasing the effectiveness of the testing session.
BP2.6	Ensuring supervision by professionals in the field of user-based testing with users with disabilities	Including expert supervision in user testing activities with users with disabilities increases the likelihood that requirements and good practices are carried out in testing [66,67]. The presence of a professional in this field who will monitor the testing sessions, develop a testing plan, and provide feedback and guidance will ensure that the testing is conducted in a structured and effective manner and that the results are accurate and reliable.
BP2.7	Involving several evaluators in the user testing process	One of the main precautions that should be taken while conducting a usability test with learners who are blind is always to include at least two evaluators: one mediator and one observer. If the same evaluator who gives instructions and mediation also tries to make detailed field notes, this person is more prone to pay attention to some usability issues [68]. Involving several evaluators and assigning them straightforward tasks in the user testing process can help ensure the testing results are accurate and reliable, especially if results are regularly reviewed, discussed, and compared, and evaluators collaborate.
BP2.8	Creating comfortable surroundings	Providing comfortable surroundings (such as a quiet and comfortable location that is free from distractions and refreshments) and accessible infrastructure has an impact on concentration and better test performance [53]. Participants who feel at ease are likelier to provide honest and detailed feedback.
BP3. Best practices after user testing		
BP3.1	Compensating participants for their contribution to user testing activities	Providing compensation to attend user testing for participants increases the assurance of participation in testing and the seriousness of involvement [62,63]. In addition to appropriate compensation that reflects the time and effort required of participants and the value of their contribution, it is essential also to show gratitude and general appreciation for their time and input.

To understand how the identified good practices cover the challenges identified in the existing literature and to create a visual representation of the two data sets, we have prepared a table where we have mapped good practices with identified challenges where applying a good practice can help solve the individual challenge or part of the challenge. Three researchers performed the mapping process with the help of a Google spreadsheet. The same layout table of best practices and challenges was created, and all researchers had the task of identifying associations between two variables: the challenges and the best practices. In the cells where a good practice can be mapped to a challenge by the researcher's opinion, researchers made a notation. Once all researchers evaluated the mapping possibilities, the results were compared. In cases where all researchers agreed on a connection between a challenge and a best practice, the mapping was automatically confirmed. In cases where researchers did not wholly agree on a link, a discussion followed, and as long as at least two researchers decided on a mapping, it was included. In cases where only one researcher identified the connection, the mapping was not included.

As can be seen from Table 12, applying certain individual practices enables solving various challenges in user-based testing with users with disabilities. Moreover, to solve individual challenges, it is also necessary to use different good practices. There are good practices that make it possible to solve several challenges. An example of such good practice is the involvement of experts in testing that involves users with disabilities. An expert in this field can help address various challenges in different user testing phases. At

the same time, in the future, it will be necessary to address some challenges by searching for additional good practices, as currently, there are few practices that could be found in the existing literature that address the difficulties recognized.

Table 12. Mapping of identified good practices to identified challenges in user-based testing with users with disabilities.

		Best Practices														
		BP 1.1	**BP 1.2**	**BP 1.3**	**BP 1.4**	**BP 1.5**	**BP 1.6**	**BP 2.1**	**BP 2.2**	**BP 2.3**	**BP 2.4**	**BP 2.5**	**BP 2.6**	**BP 2.7**	**BP 2.8**	**BP 3.1**
Challenges	C1.1												■			
	C1.2												■			
	C1.3		■										■			
	C1.4	■			■	■							■			
	C1.5												■			
	C2.1			■						■						
	C2.2	■			■	■	■						■			
	C2.3													■		
	C2.4					■	■						■			
	C2.5					■	■						■			
	C2.6													■		
	C2.7							■	■					■		
	C2.8						■	■					■	■		
	C2.9												■	■	■	
	C2.10												■	■		
	C2.11						■				■	■	■			
	C2.12												■	■		
	C2.13						■				■	■	■	■		
	C2.14													■		
	C3.1															■
	C3.2												■	■		

Note: A cell with a black background depicts the link between an individual objective and an individual best practice.

5. Discussion

In this study, based on the synthesis of existing knowledge obtained through a systematic review and analysis of 84 studies, we provide (1) an overview of the latest research in the field of user testing, where users with disabilities were actively involved, (2) an overview of the various challenges that researchers faced when involving persons with disabilities, and (3) a review of good practices based on which researchers have successfully included users with disabilities in user testing studies. The needs and expectations of end users can differ significantly depending on the type of disability. As a result, the challenges and best practices that can be applied to users with a specific type of disability can also differ. Due to the lack of research in the existing literature, it is currently difficult to develop either general guidelines for the implementation of best practices for all types of disabilities or a list of best practices associated with a specific disability. For this reason, it will be necessary to wait for new research, which can be expected in the future, given the established trend of published research in the last years.

Even though the field of usability and user experience evaluation is already well-researched in the existing literature, there are a lack of studies in this field that would comprehensively address the various challenges associated with including users with disabilities in user testing. In usability or user experience evaluation studies, when involving users with disabilities, it is necessary to understand all the challenges related to the testing method and, of course, the characteristics and obstacles of such users. In the existing literature, we observe a positive growth of studies that include users with disabilities as active participants. This outcome is undoubtedly encouraging and consistent with the

goals of various national and international directives, aiming to enable equality for all in all areas.

The results of our study showed that it would be necessary to improve the reporting of all user testing phases in scientific publications. User-based testing involves several phases, with different activities performed within the stages. For user-based testing with users with disabilities especially, planning and executing all steps well with attention to the requirements and characteristics of users' disabilities is necessary. In the first phase, which is related to testing planning, it is essential to carry out various activities, for example, preparing tasks, preparing a prototype/solution to be tested, obtaining permission from the ethics committee, recruiting, and others. In the user testing phase, there are also several related activities (e.g., welcome, pre-testing questionnaire, testing, post-testing questionnaire) to which we must pay special attention because of users with disabilities. Additionally, in the phase when user testing is completed, activities related to included users with disabilities can still be carried out (e.g., activities of obtaining feedback after analysis).

For researchers who plan to conduct user-based testing with users with disabilities in the future, it is necessary to provide all the information needed for comprehensive planning and practical testing in the article. In the existing literature, for the time being, there is a noticeably worse reporting of some phases and activities of user-based testing with users with disabilities, which will undoubtedly have to be improved in the future. One such example is the very rarely described activity related to obtaining ethical approval for conducting the study. Since users with disabilities are invited to participate in these studies, we expect to see more papers reporting how ethics committee approvals were obtained and how user testing activities should be adapted accordingly, for example, involving a detailed review of research proposals to ensure that they meet ethical and legal standards, protecting the rights and well-being of research participants, and maintaining the integrity of the research itself.

In the existing literature, we found some studies where a more significant number of users with disabilities were included in testing procedures. However, in general, a smaller number of users participate in user testing studies. Our study showed this is the same for research where users with disabilities are included. Of course, the number of users who participate in testing depends on the type of testing, testing objectives, and other criteria based on which the required number of test takers is defined. In our study, we did not analyze and classify the types of testing in the analyzed studies.

In addition to a comprehensive description of the implementation of individual phases, the authors should document good practices that contributed to the successful inclusion of users with disabilities and the successful implementation of testing. Additionally, we expect that the researchers will provide all the challenges to avoid the repetition of mistakes in future user-based testing with users with disabilities.

5.1. Theoretical and Practical Implications

The theoretical implications of the results of this study, which will be interesting especially for researchers and practitioners, are in the record of challenges and good practices that still need to be documented in this way in the existing literature. The study results will provide researchers and practitioners with one place to look at challenges and good practices, based on which they can eliminate various factors in the planning phase when planning their user evaluation studies, which can negatively impact the successful implementation of user-based testing with users with disabilities.

The results of this study have several practical Implications for different stakeholders: (1) developers who design and develop interactive solutions, (2) testers who evaluate the usability and user experience of the product, and (3) end users with disabilities who use the solutions.

The first practical implication is related to planning and developing user-friendly, useful, and accessible solutions, where user testing is essential for enabling quality solutions. Developers will learn to improve the design and development of accessible solutions for

all users—including those with disabilities. Especially for the user-based testing of the developed products, the results of this study will improve awareness about the challenges related to the inclusion of users with disabilities in end-user testing procedures. The results of this study can also help improve the testing procedures, as the knowledge provided will make practitioners better aware of good practices of active involvement in such studies. Next, the results of user testing with actively involved users with disabilities will give a better insight into all product problems related to the use of and interaction with the product. Consequently, the practical outcome will be better solutions for all users.

Another significant practical implication of the results of this study is enabling better opportunities for users with disabilities to actively participate also in user-based testing processes, which in the past, maybe also due to a lack of knowledge about how such studies need to be correctly planned and carried out, were not included. Consequently, this will also improve the possibility for users with disabilities for inclusion in all activities related to the user testing.

5.2. Limitations

As in all research, this study comes with a set of limitations. Although several digital libraries were used and five researchers were involved in searching for relevant literature, there is a chance that not all relevant studies were identified and included in the review after applying inclusion and exclusion criteria and quality assessment. The keywords used in searching for relevant literature provided studies that included users with various disability types. It is even possible that with the specified keywords, we missed some studies that included users with some specific disability type which was not included with the search string.

The time scope of research was set between 2012 and 2022. Although not much relevant research was conducted before the specified period (based on our research), there could exist papers with significant insight into the beginnings of user-based testing with users with disabilities. The articles in the reviewing or publishing process not available when writing this manuscript were also not included in the systematic literature review. There is a possibility that after the conclusion of this paper, new important articles will emerge in 2023. Classification of studies by type of disability was limited by a pre-defined list of disabilities in the form we used to collect data during the articles review. Based on the results, it would be necessary to redefine the list of types of disabilities because, according to our list, we could not classify 30 studies into 1 of the types of obstacles. In future studies, it will be necessary to prepare a better classification scheme to more effectively understand the representation of different user disabilities in the existing literature.

Within the framework of the identified challenges and best practices of involving users with disabilities in user-based testing, it is necessary to consider the limitations associated with the scope of studies published in the existing literature. The list of challenges and good practices in this study was constructed based on the data extracted from the reviewed papers only. The good practices identified in this study are not aligned with the challenges. At the time of writing this manuscript, the list of challenges is more significant, which means that further research will have to provide additional good practices to help overcome the challenges not well addressed in the existing literature yet.

5.3. Threats to Validity

There is a threat that the results of the data synthesis from reviewed literature miss some other challenges and best practices because of the probability that not all relevant primary studies were discovered during the literature search. The selection of the primary studies was guided by the set inclusion and exclusion criteria within the scope of the reported search string; therefore, it is possible that some articles were automatically excluded in the process.

There is a threat of bias in the studies that were selected for data extraction. We have performed cross-checking for randomly selected papers to decrease the bias in study

selection. However, Cohen's Kappa statistic should be used to reduce the bias and time spent in the study selection process [69].

Data extraction and classification of primary studies have been challenging due to the interdisciplinary characteristics of the field. Some subjectivity is implied in data extraction; therefore, if the study is repeated, minor variations could be expected. For this reason, we have attached the list of studies included in the review as Appendix A. To minimize the threats to internal validity related to the data extraction procedure, we used a predefined data extraction scheme, and the authors decided to discuss the problematic papers.

6. Conclusions

This study contributes to the body of research on accessible HCI, particularly in planning and conducting user-based testing that includes users with disabilities. This study synthesizes the main challenges related to the inclusion and active participation of end users with disabilities in user-based testing procedures. Based on the synthesis of knowledge extracted from 84 scientific papers identified in the existing literature, this study provides a list of good practices that should be followed when planning and conducting user-based testing with users with disabilities.

Analysis of the extracted data offered the following main findings of the study. In the existing literature, we observe a positive trend of growth in studies that include users with disabilities in the user testing process, which fills us with optimism that in the future, such users will be even better included in studies. Existing studies have primarily included users with visual disabilities and users with intellectual disabilities. Other groups with other disability types are somewhat less included, meaning future research needs more attention to include users with other disabilities such as mobility disabilities, hearing disabilities, and others.

The subsequent important finding is related explicitly to comprehensive reporting on the planning and implementation of all user testing phases. Based on a systematic literature review, we can identify deficiencies in the extensive reporting in scientific publications about the steps taken in the user testing process. In the existing articles, the researchers mostly report testing implementation, the procedures for recruiting users with disabilities, and the implementation of questionnaires after testing. However, there are far fewer comprehensively reported steps that are also very important for proper planning and execution of testing, namely the preparation of tasks to be performed by the user during testing, obtaining the ethics committee's opinion, obtaining feedback after testing, and others. Future articles about user-based testing with persons with disabilities must report all activities carried out before and after the testing and be crucial for effectively including users with disabilities in the testing processes.

The results of this study provide a list of challenges and good practices that are important in the different phases of user testing: before, during, and after testing. Results of this study showed an opportunity for further systematic mapping research, the goal of which would be to prepare a systematic mapping of challenges and good practices according to the type of disability. We also see the possibility for future research, which will enable the confirmation or validation of identified challenges and good practices in cooperation with users with specific types of disability who have practical experience with active involvement in user-based testing. Based on the practical experience of users with disabilities in user-based testing, the list of good practices will be updated and supplemented with practices we could not identify through the systematic literature review.

Author Contributions: B.Š. proposed the idea, designed the review process, searched the literature, reviewed the literature, extracted data, conducted the data analysis, and wrote the manuscript. K.K. reviewed the literature, extracted data, conducted data analysis, and wrote and revised the first draft. L.M.-N. searched the literature, reviewed the literature, extracted data, and revised the first draft. J.P. searched the literature, reviewed the literature, extracted data, and reviewed the first draft of the manuscript. M.P. performed the literature review, extracted data, prepared the data for analysis, and

wrote and revised the first draft. All authors proofread the paper. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Primary studies identified in the literature review.

ID	Authors	Year	Journal/Conference
S1	Doush [42]	2022	Universal Access in the Information Society
S2	Torrado, Jaccheri, Pelagatti, & Wold [36]	2022	Entertainment Computing
S3	Silva, Freire, & Cardoso [51]	2022	Proceedings of the 19th International Web for All Conference
S4	Nair, Olmschenk, Seiple, & Zhu [26]	2022	Assistive Technology
S5	Vincent et al. [70]	2022	Disability and Rehabilitation: Assistive Technology
S6	Alajarmeh [71]	2022	Universal Access in the Information Society
S7	Lee, Hong, Jarjue, Mensah, & Kacorri [48]	2022	Proceedings of the 19th International Web for All Conference
S8	Darin, Andrade, & Sánchez [68]	2022	International Journal of Human-Computer Studies
S9	Królak & Zając [72]	2022	Universal Access in the Information Society
S10	Fox et al. [73]	2022	JMIR mHealth and uHealth
S11	Jain et al. [74]	2022	CHI Conference on Human Factors in Computing Systems
S12	Ahmetovic, Bernareggi, Leporini, & Mascetti [75]	2022	ACM Transactions on Accessible Computing
S13	Barbosa, Hayes, Kaushik, & Wang [76]	2022	ACM Transactions on Accessible Computing
S14	Guasch et al. [50]	2022	Universal Access in the Information Society
S15	Weir, Loizides, Nahar, Aggoun, & Pollard [43]	2021	Universal Access in the Information Society
S16	Ito et al. [77]	2021	Disability and Rehabilitation: Assistive Technology
S17	Goncu & Finnegan [52]	2021	A chapter in Lecture Notes in Computer Science
S18	Lebrasseur et al. [78]	2021	Assistive Technology

Table A1. *Cont.*

ID	Authors	Year	Journal/Conference
S19	Apu et al. [79]	2021	2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI)
S20	Cimmino, Pero, Ricciardi, & Wan [80]	2021	Pattern Recognition Letters
S21	Chu, Biss, Cooper, Quan, & Matulis [44]	2021	JMIR Serious Games
S22	Yeong, Thomas, Buller, & Moosajee [81]	2021	Journal of Medical Internet Research
S23	Zhang et al. [82]	2021	Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems
S24	Kulich, Bass, & Koontz [61]	2020	Assistive Technology
S25	Leporini, Rossetti, Furfari, Pelagatti, & Quarta [83]	2020	ACM Transactions on Accessible Computing
S26	Yeni, Cagiltay, & Karasu [84]	2020	Universal Access in the Information Society
S27	Thorsen, Dalla Costa, Beghi, & Ferrarin [41]	2020	Frontiers in Neuroscience
S28	Wesselman et al. [38]	2020	The Journal of Prevention of Alzheime's Disease
S29	Yi [85]	2020	Universal Access in the Information Society
S30	Creed, Frutos-Pascual, & Williams [59]	2020	Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems
S31	Fogli, Arenghi, & Gentilin [46]	2020	Multimedia Tools and Applications
S32	Alonso-Virgos, Baena, & Crespo [86]	2020	2020 15th Iberian Conference on Information Systems and Technologies (CISTI)
S33	Husin & Lim [87]	2020	Disability and Rehabilitation: Assistive Technology
S34	Summa et al. [88]	2020	Computer Methods and Programs in Biomedicine
S35	Rocha, Paredes, Martins, & Barroso [89]	2020	Lecture Notes in Computer Science
S36	Giudice et al. [32]	2020	ACM Transactions on Accessible Computing
S37	Sato et al. [63]	2019	ACM Transactions on Accessible Computing
S38	Rocha, Gonçalves, Fernandes, Reis, & Barroso [90]	2019	Expert Systems
S39	Arrue, Valencia, Pérez, Moreno, & Abascal [19]	2019	International Journal of Human–Computer Interaction
S40	Efthimiou et al. [91]	2019	Technologies
S41	Mattie, Wong, Leland, & Borisoff [54]	2019	Disability and Rehabilitation: Assistive Technology
S42	Guo, Kong, Rivera, Xu, & Bigham [92]	2019	Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology
S43	Šumak, Špindler, Debeljak, Heričko, & Pušnik [33]	2019	Journal of Biomedical Informatics
S44	Wittich, Jarry, Morrice, & Johnson [93]	2018	Optometry and Vision Science
S45	Gonçalves, Rocha, Martins, Branco, & Au-Yong-Oliveira [30]	2018	Universal Access in the Information Society
S46	Day, Jokisuu, & Smith [67]	2018	Lecture Notes in Computer Science
S47	Carvalho, Dias, Reis, & Freire [47]	2018	Proceedings of the 33rd Annual ACM Symposium on Applied Computing
S48	Rossetti, Furfari, Leporini, Pelagatti, & Quarta [94]	2018	Procedia Computer Science
S49	Smaradottir, Håland, & Martinez [56]	2018	Mobile Information Systems

Table A1. *Cont.*

ID	Authors	Year	Journal/Conference
S50	Alonso-Virgós, Rodríguez Baena, Pascual Espada, & González Crespo [57]	2018	Sensors
S51	Agulló, Matamala, & Orero [45]	2018	Hikma
S52	Reichinger et al. [95]	2018	ACM Transactions on Accessible Computing
S53	Kozlowski, Fabian, Lad, & Delgado [96]	2017	Archives of Physical Medicine and Rehabilitation
S54	Käthner et al. [39]	2017	Frontiers in Neuroscience
S55	Deems-Dluhy, Jayaraman, Green, Albert, & Jayaraman [66]	2017	PM&R
S56	Sato et al. [62]	2017	Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility
S57	Senan, Wan Ab Aziz, Othman, & Suparjoh [97]	2017	MATEC Web of Conferences
S58	Zhang, Zhou, Uchidiuno, & Kilic [98]	2017	ACM Transactions on Accessible Computing
S59	Filippi & Barattin [64]	2017	Lecture Notes in Mechanical Engineering
S60	Pereira & Archambault [99]	2016	Lecture Notes in Computer Science
S61	Rocha, Paredes, Barroso, & Bessa [100]	2016	Lecture Notes in Computer Science
S62	Rocha, Reis, Rego, Moreira, & Faria [101]	2016	2016 11th Iberian Conference on Information Systems and Technologies (CISTI)
S63	Paulino et al. [102]	2016	Proceedings of the 7th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-exclusion
S64	Lopes et al. [58]	2016	IRBM
S65	Mirri, Prandi, & Salomoni [103]	2016	2016 13th IEEE Annual Consumer Communications & Networking Conference (CCNC)
S66	Morales-Villaverde, Caro, Gotfrid, & Kurniawan [104]	2016	Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility
S67	Gamecho et al. [105]	2015	IEEE Transactions on Human-Machine Systems
S68	Godinho, Condado, Zacarias, & Lobo [106]	2015	Behaviour & Information Technology
S69	Savva, Petrie, & Power [107]	2015	Lecture Notes in Computer Science
S70	Navarrete & Lujan-Mora [108]	2015	2015 International Conference on Interactive Collaborative and Blended Learning (ICBL)
S71	Aizpurua, Arrue, & Vigo [60]	2015	Computers in Human Behavior
S72	Miralles et al. [53]	2015	Frontiers in ICT
S73	Lee, Hong, An, & Lee [55]	2014	Service Business
S74	Ivanchev, Zinke, & Lucke [109]	2014	Lecture Notes in Computer Science
S75	Pascual, Ribera, Granollers, & Coiduras [49]	2014	Procedia Computer Science
S76	Rodriguez-Sanchez, Moreno-Alvarez, Martin, Borromeo, & Hernandez-Tamames [110]	2014	Expert Systems with Applications
S77	Zickler, Halder, Kleih, Herbert, & Kübler [24]	2013	Artificial Intelligence in Medicine
S78	McDaniel, Viswanathan, & Panchanathan [111]	2013	2013 IEEE International Conference on Multimedia and Expo (ICME)
S79	Schroeter et al. [65]	2013	2013 IEEE International Conference on Robotics and Automation

Table A1. *Cont.*

ID	Authors	Year	Journal/Conference
S80	Keskinen, Heimonen, Turunen, Rajaniemi, & Kauppinen [40]	2012	Interacting with Computers
S81	Roentgen, Gelderblom, & de Witte [112]	2012	Assistive Technology
S82	Brizee, Sousa, & Driscoll [37]	2012	Computers and Composition
S83	Fuglerud & Røssvoll [113]	2012	Universal Access in the Information Society
S84	Hassell, James, Wright, & Litterick [114]	2012	Journal of Assistive Technologies

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