Usability Evaluation Methods of Indoor Navigation Apps for People with Disabilities: A Scoping Review

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***Abstract*— More than 25% of adults in the U.S. have one or more disabilities. These disabilities hinder one's ability to complete necessary everyday tasks such as navigating independently in indoor environments. Various tools have been designed and tested to aid disabled persons while navigating indoors including smartphone apps. However, many of the designed interfaces are not extensively researched and therefore might not meet the needs of end users. The objective of this study was to determine the types of usability evaluation methods used for indoor navigation app interfaces designed for people with disabilities and recommend a comprehensive usability method for future studies. A scoping literature review was conducted on different databases. Fifty-one articles met the inclusion criteria and were included in the analyses. Results revealed that a majority of studies used subjective data as a measure of usability, several conducted usability tests with a limited number of end users, and there was a lack of comprehensive usability evaluation methods. These limitations often led to general validations of whether the interface had acceptable usability, but they did not provide specific feedback for interface improvements. Based on these findings, a list of recommendations for future studies is provided to better assess usability of indoor navigation apps for people with disabilities.**

Keywords*— *indoor navigation, interface, usability evaluation, disability

I. Introduction

Disabilities hinder a person's ability to complete everyday tasks. According to the Centers for Disease Control and Prevention, 26% of adults in the US live with at least one disability [1]. A disability refers to "the interaction between individuals with a health condition (e.g., cerebral palsy, down syndrome and depression) and personal and environmental factors (e.g., negative attitudes, inaccessible transportation and public buildings, and limited social support)" [2]. Some of the most prominent disabilities in the US are mobility impairments (MI), cognitive impairments (CI), hearing impairments (HI), as well as blind and visual impairments (BVI) which make up 13.7%, 10%, 5.9%, and 4.6% of adult disabilities respectively [1]. In addition, about 40% of disabled persons have multiple disabilities [3] and 2 out of 5 older adults (OA) above 65 years old, experience a disability [1].

Disabilities can negatively impact a person's ability to complete necessary daily activities. Navigating in outdoor and indoor environments is an area where disabled persons often need assistance due to a decreased perception of their environment [4]. Therefore, assistive technologies have been developed and implemented to help improve disabled person's everyday lives. Specifically, various smartphone apps have been developed to aid disabled persons while navigating indoors (e.g., [4]). Interface design of indoor navigation apps for people with disabilities is an important consideration to ensure that assistive technology can make navigation easier for the user rather than more complex and frustrating. While various studies have developed indoor navigation apps to assist disabled users, this study focuses on the usability methods used to evaluate such apps.

Regarding target groups, this study focuses on indoor navigation apps for users with BVI, HI, MI, CI, no impairments (NI), or OA. NI individuals were included to make the app as inclusive as possible. These disability groups were selected based on their prevalence in the US. More specifically, the objectives of this study were to: (1) determine the most common usability methods and measures used to investigate indoor navigation apps for BVI, HI, MI, CI, NI, or OA (2) identify the limitations of these usability methods, and (3) propose the best usability methods to evaluate the interface of an indoor navigation app designed for multiple target end users.

II. Method

To conduct this scoping review, a seven-step approach was used. First, the topic and scope were defined as research studies that tested the usability of an indoor navigation app. Second, the databases used to conduct the search were selected including: Engineering Village (Compendex and Inspec), Web of Science (WOS), Institute of Electrical and Electronics Engineers (IEEE), Association of Computer Machinery (ACM), and Google Scholar. These databases were selected due to their broad and high quality coverage of literature in engineering and other disciplines [5, 6]. Third, keyword groups were established to yield optimal search results that are aligned with the determined research topic. The established groups were *indoor navigation*, *target user*, *test types*, and *app*. Some of the keywords that were used in each group are listed below.

- *Group 1: Indoor Navigation*: "Indoor Navigation" OR "Indoor Positioning System*"
- *Group 2: Target User:* "Blind" OR "Visually Impaired" OR "Visual Impairment*"; "Mobility Impaired" OR "Mobility Impairment*" OR "Physical Disability*"; "Hearing Impairment*" OR "Hearing Loss*" OR "Deaf"; "Cognitively Impaired" OR "Cognitive Disability*"; OR "Older Adult*" OR "Elderly"
- *Group 3: Test Types:* "Usability Evaluation*" OR "Usability" OR "Survey*" OR "Questionnaire*" OR

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"Focus Group*" OR "User Testing" OR "Experiment*" or "Interview*" OR "Observation*" OR "Think-Aloud"

- *Group 4: App:* "App*" OR "Application*"

Fourth, the search strategy was established and implemented to search each database six times, one time for each target user group. Each search consisted of all the keywords from groups one, three, and four and one type of user from group two. Fifth, the inclusion and exclusion criteria were established to determine if the reviewed literature was related to the search topic. Inclusion criteria consisted of studies that conducted some form of a usability test of an indoor navigation app on a smartphone. The exclusion criteria consisted of studies that did not have indoor navigation capabilities, were conducted in virtual reality (VR) or simulation, did not test the usability of an app, did not use a smartphone, or did not look at any form of interface design. Sixth, the filtering process of the literature results was conducted. After reading the full article, the relevant papers were kept for inclusion in this literature review. The seventh and final step was to conduct manual searches. In this step, references from included articles were reviewed and added based on their relevance.

III. Results

The literature review revealed 51 relevant articles that are summarized by their target user group in Table 1.

A. Target End Users

Of the 51 articles included, 49 studies designed an app to assist one disability group. A majority focused on BVI end users, with 35 studies, exclusively designing apps just for BVI users. There were 10 studies that focused on NI users, two for CI, one for OA, and finally, only one study focused on individuals with HI.

B. Participants

Thirty-seven (37) studies used participants that aligned with their target end users. Twelve studies did not evaluate the interface with the end users at all, used less than 5 end users, and/or tested with users outside of their target population. Most of these occurrences were seen in apps designed for BVI users where sighted participants were used to simulate BVI users by

TABLE 1. SUMMARY OF RELEVANT STUDIES OF INDOOR NAVIGATION APP USABILITY EVALUATIONS

Target User Group	Usability Methods	Usability Measures	Main Findings	Reference
BVI	User testing, questionnaire, interview, think-aloud, field study, personas	Comments, subjective ratings (e.g., perceived helpfulness), feedback, performance (e.g., errors, TCT), navigation efficiency index, SUS, NASA-TLX	Validated the product is deployable and has desirable usability, found necessary changes to increase the usability of the app's interface (e.g., informing the users where room doors are), compared usability of multiple apps	[4, 7-40]
HI	User testing, interview	Feedback	Found several interface improvements (e.g., enlarging the popup window that allows users to select which navigation question they have)	[41]
MI	NA	NA	NA	NA
CI	User testing, questionnaire, interview, think-aloud	Comments, opinions, SUS, performance (e.g., errors, TCT time), Santa Barbara Sense of Direction Scale, spatial knowledge	Validated the systems' usability, found a list of interface design considerations (e.g., use landmark pictures, simplify navigation directions, avoid interface distractions)	[42, 43]
OA	NA	Suggestions, comments	Found a few changes to improve interface usability to better fit the needs of elderly people (e.g., adding the word 'help' under the icon for emergency calls, reducing amount of information on the screen)	[44]
NI	User testing, questionnaire, interview, think-aloud	Comments, SUS, subjective ratings (e.g., of user experiences and trust), TAM, NASA-TLX, performance (e.g., walking speeds and reply accuracy), technical self-efficacy questionnaire, screen movements, feedback, fixation, readability (e.g., users understanding found from think-aloud coding), legibility (e.g., text detection speed and accuracy), cognitive processing speed ranking	Validated the apps' usability and usefulness, found the apps' interface need improvements (e.g., incorporating more landmark pictures to assist with navigation orientation and updating icons to recognizable symbols), identified specific interface updates	[45-54]
Multiple User Groups	User testing, questionnaire	Ratings (e.g., of app's effectiveness), performance (e.g., evacuation time)	Validated the apps' effectiveness and usability	[55, 56]

[a.] System Usability Scale (SUS), NASA Task Load Index (NASA-TLX), not available (NA), technology acceptance model (TAM), task completion time (TCT)

being blindfolded or by obstructing their phone screen. Also, three studies did not explicitly state whether their participants were able-bodied or not (e.g., [8]).

C. Usability Methods

Forty (40) studies used more than one usability method, 10 used one usability method, and one study did not specify their method. User testing, questionnaires, and interviews were the most frequently used methods making up 38, 29, and 24 studies respectively. While user testing was the most frequently used method, many studies only used the user testing to familiarize the users with an app's interface. The other usability methods were significantly less frequent where seven studies used think-aloud, three used field tests, three used surveys, two used focus groups, and one used personas. There were instances where the studies claimed to have used field tests but based on the authors' knowledge, some of them were summarized as user testing (e.g., [15]). The most frequently used usability methods to evaluate indoor navigation apps are discussed in more detail in Table 2. The table summarizes major advantages and limitations of each usability method found in previous indoor navigation studies. Additionally, it presents if each method included subjective or objective measures. More information about usability methods can be found in [57].

Although many studies were included that looked at the usability of indoor navigation apps, few focused on the usability as a main aspect of the study. Several studies used user testing that was aimed to investigate the functionality more than the usability of these indoor navigation apps. The user tests often measured objective data such as the number of errors, success rates, and task completion time. However, these measures were most often used to test an app's functionality rather than the interface's usability. The subjective measures alongside user testing usually came from another usability method such as questionnaires. For example, in a study with BVI users [22], all of the evaluated factors were related to the app's functionality such as the time it took for a participant to reach their destination or whether the system made an error. However, the usability of the system was only investigated through a subjective analysis that was conducted after the user testing using SUS. The SUS score indicated that the system achieved good usability (SUS score of 92) which suggested that the app was easy to use.

There was a wide range of questionnaires and interviews used to evaluate the indoor navigation apps. Questionnaires ranged from pre-established questionnaires that have been included in previous studies to in-house questions generated by the researchers. While interviews mainly consisted of general questions that asked questions like how easy it was to use the system, some prompted more specific answers such as asking the participant to identify the most difficult part of the task (e.g., [29]). Last, the think-aloud method was used by studies for getting insights into the participants' feedback of the app rather than their thought processes and where the app may be cognitively overloading them (e.g., [13]).

TABLE 2. MOST COMMON USABILITY METHODS FOR INDOOR NAVIGATION APPS

Usability Method	Advantages	Limitations	Subjective or Objective
User testing	Easily deployable, provides insight from the end users, reveals interface issues before app implementation	Users are not interacting with the app in a real-world scenario	Objective and subjective
Questionnaire	Easily deployable, can get participant's opinions about specific inquiries, pre-established questionnaire results can be compared to others' findings	Can be too general and not provide insight into where the usability issues are, users may interpret questions different than intended	Subjective
Interview	Easily deployable, can get detailed responses, guide the conversation	Quality of data heavily relies on the interviewer	Subjective
Think-aloud	Gain insight into cognitive processing overload, issues the participant may not remember to mention later	May interfere with participants' ability to complete the main task	Subjective

D. Usability Measures

Among the 51 studies, 25 used both subjective and objective usability measures and 24 used only subjective measures. Additionally, one study used only objective measures and one did not specify their usability measures. Some of the most common subjective measures came from subjective ratings collected through questionnaires. The most common pre-established questionnaire used was SUS which measured users' opinions on the app's usability. Others used measures including NASA-TLX, to measure subjective workload, and TAM, to measure subjective acceptance of the app (e.g., [18]). Also, users' comments of the apps' issues and possible improvements were frequently used as subjective measures of usability. Many studies only mentioned subjective data as usability measures and not performance data. Performance data were often considered measures of the app's functionality, but it could also provide insight into the usability. For objective measures, the most common usability measures were performance measures such as task time and errors encountered while using the app.

E. Main Findings

The main findings of each study were organized based on whether it validated if the app's usability was acceptable or if it provided interface improvements. It was found that 24 studies focused on validating the app while 19 found specific improvements or needs for the app to improve its usability. Six studies that both validated the interface and suggested

improvements and two studies that did neither validated nor provided any improvements to the interface (e.g., [12]).

IV. DISCUSSION

The findings suggested that very few apps focused on multiple disabilities [55, 56], and none designed for all target users of this study, which are the most common disabilities in the US. Additionally, when testing these apps, previous studies did not always use the end users as study participants. It is important to use the end users while testing the interface design because they can be a representative sample for target populations and provide insights that an able-bodied person cannot. For example, some studies used blindfolded sighted participants instead of BVI users (e.g., [12]). Sighted users are not adapted to a life without vision; therefore, might not fully understand how a BVI user may interact with technology while trying to navigate indoors. Additionally, many studies did not evaluate the app's usability thoroughly and it was often an afterthought to a functionality test. Lastly, most of the usability methods and measures often resulted in subjective information which led to the results mainly validating the usability of the app rather than providing improvements to its design. The most common usability methods that have been used on indoor navigation apps and their limitations are discussed below.

User Testing: Only using subjective data to assess usability during user testing does not allow the researchers to gain insight into what to change in the app or how to do it, but rather validating whether the usability of their interface is acceptable. Using objective measures such as performance measures related to interface usability will provide more valuable insight into where the major issues may be occurring. Using both subjective and objective measures during user testing allows the researcher to investigate issues that may have not stuck out to the users as well as identify the issues participants are unconscious of or may not remember to mention. Objective measures can highlight areas that need improvements based on performance measures such as the number of errors even if it was not mentioned as an issue by the participant during subjective evaluations. On the other hand, subjective measures provide insight into usability issues that may not negatively impact a user's performance. Last, using the two measures in conjunction provides a more complete picture of where and what the main usability issues are.

Questionnaire: Questionnaires are a subjective measure that can lead to both general and specific feedback from participants. Using pre-established questionnaires can be beneficial when trying to determine if an app's usability and mental demand is acceptable compared to other apps on the market. However, to capture specific issues and areas for improvement within an app's interface, using more targeted questionnaires is required. In-house questionnaires can be beneficial to ask about targeted areas of an interface. This advantage can easily be missed if the questions asked are too general such as "did you find the app useful?". If an in-house questionnaire is used, it would be beneficial if the questions were more specific to areas and features of the app. An example of this would be "did you find the map useful?" and following up with "if so, which parts did you like?".

Interview: Interviews, like questionnaires, are highly subjective but introduce more of a conversation. However, there can be a missed opportunity if the interview is too general and the interviewer is not highly skilled. Interviews should use both general and specific questions to understand the participant's opinions about the app and its features but also leave room for the interviewer to ask them to expand and provide feedback and suggestions when needed. Additionally, while the interview is subjective, it could be based on the findings of objective measures. If the researcher observes while participants interact with the app, it is beneficial if they focus some of the questions on areas the participant seemed to struggle with (e.g., ask about parts of the interface they slowed down or made mistakes).

Think-aloud: Think-aloud method also provides subjective measures of participants thoughts and opinions while they are interacting with the app. This method is useful if participant's thoughts are analyzed thoroughly through thematic analysis. Using this method provides insight into the specific areas when participants did not know how to use the app, experienced potential cognitive overload, or were confused. Think-aloud provides insight into unconscious issues that are not revealed in other forms of subjective measures.

A. Which Usability Methods to Use?

The findings suggested that using a mixture of usability evaluation methods, measures, and participants would be the most beneficial for future indoor navigation usability assessments with multiple target users. A three-phase usability evaluation process is recommended as described below.

a) Phase 1- Early Heuristic Evaluation with Experts: This phase can be completed early in the design process with five usability experts using a pre-established checklist based on usability principles (e.g., [58]). Only five participants are needed to discover about 80% of the usability issues [59]. The participants will interact with the app based on specific use-case scenarios to ensure they use the main functionalities. It is important to collect both subjective and objective data at this phase to ensure a comprehensive analysis. Subjective measures can result from the think-aloud method to provide insight into their cognitive processes. Additional subjective measures could include interviews to ask the participants both general and specific questions pertaining to the app's interface. To collect objective measures, all sessions can be recorded to observe performance measures, such errors. At the end of all scenarios, the participant can fill out the usability checklist to determine which usability principles are violated on the app's interface. To put more context to this questionnaire, the researcher and participant can discuss the usability principles the participant marked as violated and brainstorm possible solutions to resolve the issues. After analyzing all findings, the interface can be updated based on the common themes among all participants.

b) Phase 2- User Testing with End Users: Next, testing can be completed with five end users from each target group to

discover usability issues [59]. Again, at this stage participants can go through use-case scenarios while using the think-aloud method to gain insight into the users' thought processes. Interviews can be conducted throughout the experiment for subjective measures on the users feeling towards the app. When complaints are mentioned, the researcher can follow up to get a detailed response of what the user did not like and ask how the user thinks the issue could be resolved. This technique will avoid general answers that do not point to specific areas of improvement in the interface. Subjective measures can also be used to determine if the app has been improved since the heuristic evaluation. Using the most common issues found from the heuristic testing, participants can answer whether they felt the usability principle was violated or not, and if it was, how it could be resolved. For objective measures, performance measures can be captured through video recordings to give insight into which features are more or less intuitive. The results can be analyzed and the interface should be updated to accommodate the issues before moving on to the next phase.

c) Phase 3- Field Testing with End Users: Field testing with five end users from each target group can be conducted to investigate the usability in the real-world environment [59]. At this stage, participants are not given specific use case scenarios but rather just instructed to use the app to navigate any destination. Objective measures can include performance measures such as task time and number of errors. At the end of experimentation, the researcher can collect subjective data from an interview and questionnaire. This data collection should be done at the end of experimentation to not interrupt the participant during the field test to ensure the test is as close to a real-world scenario as possible. The interview can capture participants feelings towards the app's usability. The questionnaire can investigate if the most common issues from user testing were resolved. Last, final interface updates should be conducted, and it should be concluded if the interface is ready for implementation.

A. Limitations

Some studies only considered the subjective measures for drawing conclusions about the interface's usability. However, the authors' expert judgement was used to determine when objective measures seemed to provide insight into interface usability, and it was included in this review. Additionally, most studies investigated BVI users so the other target user groups of interest were not well explored. Therefore, the recommendations provided by this study should be used with caution for other target groups.

V. CONCLUSION

The findings suggested that a majority of studies did not focus on testing the app's usability and only used subjective measures to validate the system's overall functionality. However, it is recommended to include both subjective and objective usability measures in each stage of the usability evaluation to lead to a stronger conclusion about the system's usability and where the biggest issues may be occurring.

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