Embracing Errors: Examining How Context of Use Impacts Blind Individuals' Acceptance of Navigation Aid Errors

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ABSTRACT
Prevention of errors has been an orienting goal within the field of Human-Computer Interaction since its inception, with particular focus on minimizing *human* errors through appropriate technology design. However, there has been relatively little exploration into how designers can best support users of *technologies* that will inevitably make errors. We present a mixed-methods study in the domain of navigation technology for visually impaired individuals. We examined how users respond to device errors made in realistic scenarios of use. Contrary to conventional wisdom that usable systems must be error-free, we found that 42% of errors were acceptable to users. Acceptance of errors depends on error type, building feature, and environmental context. Further, even when a technical error is acceptable to the user, the misguided social responses of others nearby can negatively impact user experience. We conclude with design recommendations that embrace errors while also supporting user management of errors in technical systems.

Author Keywords
Device errors; visual impairments; blindness; assistive technology; navigation; stigmatization; disability;

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K.4.2. [Computers and society]: Social issues – *assistive technologies for persons with disabilities.*

INTRODUCTION
Independent navigation is critical to people who are blind or visually impaired. Traditional navigation aids, like white canes and guide dogs, coupled with orientation and mobility training are fundamental to enabling access to education, employment, and independent living. In technical fields, development of complementary digital navigation aids has been ongoing for over four decades (e.g., [5,9,17,23]). This is a testament both to how important these technologies are as well as how much is left to be accomplished.

Historically, both research (e.g., [16,17]) and commercial (e.g., BlindSquare [36], Ariadne GPS [35]) navigation technologies have been primarily focused on outdoor navigation. These approaches have been able to leverage existing technology, such as GPS, and tap into already existing repositories of information (e.g., maps, bus stops, and points of interest).

Indoor navigation poses unique technical challenges. Unlike outdoor navigation technologies, indoor systems typically cannot access maps of spaces. As a result, proposed approaches often require costly environmental modifications, like the addition of beacons. Researchers are now turning to approaches such as computer vision as a more practical solution [18]. As an alternative, computer vision does not require costly changes to building infrastructure. However, these systems are known to make errors, and there is little to no understanding of how foreseeable errors will impact user experience.

The question that drives this research is: how do error type and context of use affect user perception of whether an indoor navigation aid is acceptable? Extending our preliminary study [1], we conducted a survey with 57 visually impaired individuals about how they would react to 10 different scenarios in which computer vision errors were made by a generic navigation aid. We then conducted follow-up focus groups with 16 survey participants to more deeply explore how themes raised in our survey related to real life experiences. We found that 42% of errors were actually acceptable to users and that various technical and social factors affected user acceptance (Figure 1). Interestingly, even when the user accepted a device error, concerns about how strangers might perceive and treat them often surfaced. We conclude with recommendations for how technology design can more actively involve visually impaired users in managing device errors.

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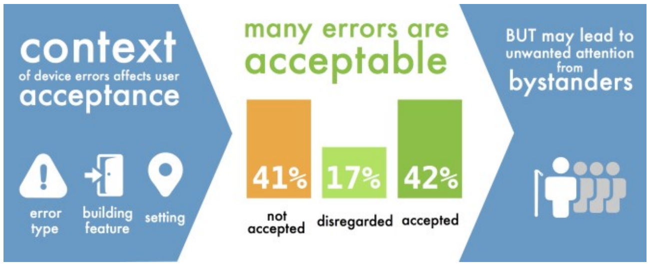

Figure 1. Findings from our survey suggest that many device errors are acceptable depending on elements of the context, like the type of device error made. Participants accepted 42% of all device errors in our survey (41% of errors were not accepted and 17% of errors were disregarded). Device errors may also lead to unwanted attention from bystanders.

RELATED WORK

This work contributes to existing literature in the domains of blind navigation and the social acceptance of assistive technology (AT).

Technology Supporting Blind Individuals in Navigation

Researchers have explored the design and development of assistive technologies to support individuals who are blind with independent navigation for over four decades (e.g., [5,9,17,23]). Proposed approaches have come in a variety of mobile form factors including smartphone and wearable computers, head mounted displays [13], and smart canes [25]. Researchers have also proposed a variety of methods for localization including the use of digital maps or location data, augmenting environments with beacons, using computer vision to identify landmarks [18], and sonar [4]. Researchers have also proposed and evaluated different interface designs and output modalities for navigation technologies (e.g., [6,13,16,20]). These methods have often been evaluated through laboratory or user tests, with evaluation results taking the form of device accuracy rates, user success rates, or user task completion time (e.g., [19,23.24,32]).

Fallah et al. [12] proposed a smartphone-based navigation system designed to work in indoor environments. They used a combination of virtual maps with descriptions of tactile landmarks (e.g., doors), and sensor data combined with user input for user localization. After a six-person user study, the authors reported a success rate of 85%.

Ahmetovic et. al. [2,3] proposed a smartphone-based system that used Bluetooth beacons to provide turn-based directions and indoor and outdoor points of interest. They conducted a six-person user study and found that participants were mostly able to recover from navigation errors while using the system. However, the meaning of these errors in real-world contexts was not explored.

Panëels et al. [20] designed and evaluated a smartphone-based system suited for in situ exploration that provided users with existing points of interest while also allowing users to create their own. After an initial six-person user study measuring task completion time and two long-term deployments of the system, the authors reported a negative correlation between device errors and confidence in the system, opinions of system accuracy, and interest in continued use of the system. They highlight the need for navigation technologies to be tested in real-world contexts.

Previous work demonstrates innovative and novel navigation technologies. However, little research has been done to explore how users perceive device errors, and how context of errors may impact device acceptance. A downside of relying primarily on error rates as a metric to determine success is that real world implications associated with device errors may often be overlooked. Like most recognition technologies, navigation aids make errors. Rather than contributing a new technology to this rich corpus, our purpose is to explore how errors in diverse contexts are perceived and handled by users.

Social Consequences of Assistive Technology Use

Past research has found that there are often social dimensions of AT adoption and use. People with visual impairments navigate the world differently than their sighted counterparts [11,33,34]. However, people with different abilities interact with each other on a regular basis. Kane et al. [14] explored how individuals with visual and motor impairments select, adapt to, and use mobile technology and noted that AT use can also mean reduced privacy for the user. Williams et al. [34] conducted 30 interviews with visually impaired individuals and found that social interactions with others were inevitable for visually impaired navigators. Branham and Kane found that many individuals with visual impairments face a difficult challenge of balancing accessibility needs with maintaining social relationships, both at home [7] and the workplace [8].

Previous research from Shinohara has shown that social context can impact an individual's decision to use an AT [26,27,28] and that some assistive devices may bring unnecessary attention to the user's disability [29]. These findings have led to a call for designers to create assistive technologies that are acceptable in social situations [30]. Profita et al. [22] later explored social acceptability and found that sighted passersby were more accepting of head-mounted displays if they were aware that they were being used for an assistive purpose.

Errors and Assistive Technology Abandonment

Previous research has identified a relationship between assistive device performance and the need for users to develop mitigation strategies (e.g., take troubleshooting steps, have the device repaired, etc. [14] or abandon the device entirely.

After surveying 227 individuals with disabilities, Phillips and Zhao found that nearly 30% of assistive devices (mobility aids most frequently) were completely abandoned. They identified four significant predictors of AT abandonment: effectiveness, affordability, operability, and dependability.

Scenario	*Scenario Description*	*Error*	*Building Feature*	*Contextual parameter extremes included*
S1	Travelling with colleagues in airport. Device directs user to restroom that is not there.	FP	Restroom	Dense, unfamiliar setting, family/friends around, professional setting, only you notice
S2	Meeting colleagues in Starbucks. Device does not announce store logo.	FN	Store logo	Sparse, familiar setting, family/friends around, professional setting, only you notice
S3	Navigating an office during the first week at new job. Device does not announce door to conference room.	FN	Door	Dense, unfamiliar setting, strangers around, professional setting, only you notice
S4	Attending a large convention for work. Device directs user to incorrect restroom.	MIS	Restroom	Sparse, familiar setting, strangers around, professional setting, only you notice
S5	Attending a business meeting for work. Device does not announce door to exit.	FN	Door	Dense, unfamiliar setting, family/friends around, professional setting, only you notice
S6	Attending a concert. Device directs user to escalator that is not there.	FP	Stair / Escalator	Dense, familiar setting, strangers around, personal setting, others notice
S7	Attending a movie theater with visually impaired friends. Device directs user and friend to incorrect restrooms.	MIS	Restroom	Sparse, familiar, family/friends around, personal setting, others notice
S8	Attending a sporting event while on vacation. Device does not announce the presence of escalators.	FN	Stair / Escalator	Dense, unfamiliar, strangers around, personal setting, others notice
S9	Attending a large meeting with blind attendees. Device directs user to the incorrect store.	FP	Store logo	Sparse, familiar, family/friends around, personal setting, others notice
S10	Attending a party with family. Device announces a door that is not there.	FP	Door	Sparse, unfamiliar, family/friends around, personal setting, only you notice

Table 1. Summary of scenarios used in the survey. Table includes scenario number, a brief description of each scenario, the error type present, the building feature being identified, and the five contextual parameter extremes included. False Negative = FN, False Positive = FP, Misidentification = MIS

Dependability includes device performance (effectiveness, reliability, durability, comfort, safety, ease of use), which can be associated with errors [21]. Kintsch and DePaula [15] later created a framework which identified features attributing to AT abandonment. They noted that an individual's tolerance for frustration may impact whether a device is abandoned and also that some users may be more sensitive to failure and prefer errorless learning experiences. We examine the ways in which context may impact user acceptance of device errors.

METHODOLOGY

Scenario-based Survey

To investigate how device errors impact user acceptance in realistic settings, we designed a scenario-based survey. Through both open and closed questions, participants explained how they would react to scenarios in which errors were made by a generic navigation technology.

Survey Design

To give participants a context for the survey, we began by describing a wearable navigation device that uses cameras to identify four different building features: doors, bathroom signs, store logos, and stairs/escalators.

We then presented participants with a set of realistic scenarios, each featuring an error made by the navigation device (Table 1). Only 10 scenarios were used to limit participant fatigue.

Three types of errors were featured across scenarios with regard to identifying building features: false positive (FP), false negative (FN), and misidentification (MIS). For example, if the navigation device detects a bathroom, but there is no bathroom present, this is a FP error. If it detects a female bathroom when it is in fact a male bathroom, this is a misidentification error.

Every scenario also contained one of two extremes across five parameters that captured context: crowd density, familiarity with location, people in crowd, social setting, and who noticed the error (Table 2). These scenario contexts and parameters were chosen based on prior research documenting the impact of social setting on AT use [8,26,28], including how public and professional settings can be more inaccessible than intimate and personal settings, and the pervasive concern of proving one's independence to others. Parameters were also informed by the personal experience of the first author, who is a white cane user, that familiar environments pose fewer difficulties than unfamiliar and that sparse crowds better support non-technical navigation than dense.

Building features, error types, and context parameters were evenly distributed among the ten scenarios to the extent possible. False positive and false negative errors were used four times each. Misidentification was used twice (unique to restrooms). Each contextual extreme was used five times. Restrooms and doors were used three times each. Store logos and stairs/escalators were used twice.

Context Parameter	*Extremes*
Crowd density	Sparse vs. dense
Familiarity with location	Unfamiliar vs. familiar
People in crowd	Strangers vs. friends/family
Social Setting	Professional vs. personal
Who noticed the error	Only you vs. others

Table 2. Contextual parameters and associated extremes used in survey scenarios. Contextual parameters were evenly distributed among all ten scenarios. Each contextual extreme was used five times total. One extreme per contextual parameter used for each scenario.

Example Scenario: "Your company has sent you to a business meeting at a hotel you have never been to before [Unfamiliar environment]. You are seated in a large room with many other professionals [Professional setting, Dense crowd, Strangers present]. During a speaking session, you excuse yourself to make a phone call. While trying to exit the room, your navigation device does not recognize the closed door and remains silent [Feature: Door; Error: FN]. You pass the door and continue walking towards the other side of the room. While searching for the exit, a meeting attendee stops you and asks what you are looking for [Others noticed the error]."

Following the presentation of each scenario, participants were asked open questions about how they would react to the device error and what steps they would take to work through the situation:

Open questions: "How would you react to the device's error? What steps would you take to work through this situation?"

Next, participants were asked a closed question to rate how likely they were to continue using this device in the future on a 7-point Likert item.

Closed question: "How likely are you to continue using the device after this experience? Type a number from 1 to 7 where 1 is 'not at all' and 7 is 'definitely.'"

Our survey went through two rounds of pilot testing with five blind participants to ensure clarity and relevance. Participants were recruited from known contacts in previous studies as well as through snowball sampling. The final survey was deployed online and each participant received all 10 scenarios in a random order. Participants were instructed to consider scenarios as individual and not successive. Minors were given an age-appropriate version of the survey in which work-related professional scenarios were replaced with school-related scenarios.

Survey Participants

We received 57 survey responses (38 female, 17 male, two preferred not to disclose). Participant ages ranged from 10-57 years of age (avg. 26). 50 participants used a white cane as their primary mobility aid (three also relied on a service animal, one also used a wheelchair). Three participants used a service animal as their primary mobility aid, three used no mobility aid at all, and one did not disclose. We refer to survey participants as "P01" to "P57."

Analysis of Survey Data

All 57 participants responded to all ten open ended questions (one per scenario), yielding 570 descriptive responses. Two researchers independently reviewed and thematically coded each response. Codes were later reconciled to reach an agreement on a unified list of 14 codes (Cohens Kappa .76). Codes were then organized into six high level categories (axial codes) to identify relationships between participant responses (Table 3). Categories are not mutually exclusive due to the fact that some scenario responses represented multiple themes. All counts of qualitative data are referred to as "mentions."

Recent research has shown evidence of positive bias in Likert-type items in the context of AT evaluation [31]. To strengthen confidence in our findings, analysis focused on qualitative responses, and looked to quantitative responses for triangulation purposes only. All quantitative data from Likert ratings are reported as percentages.

Focus Groups

We followed our online survey with two focus groups to further increase confidence in and elaborate on survey findings. Participants were asked to talk about their experiences with navigation technology and with navigation errors like those described in our survey. Participants were also asked to explain their reasoning behind their responses to selected survey scenarios.

Focus group discussions complemented survey responses by eliciting how participants had responded to errors made by navigation aids in the past. All focus group participants were attendees at a summer camp which taught orientation and mobility skills, including the use of navigation technologies. Participants were therefore in a position to provide insightful commentary and examples regarding errors in navigation, given that they had spent over one month navigating in various settings and reflecting on navigation experiences with each other. All quotes selected from focus group participants are based on prior experiences.

Category	*Associated Codes*	*Count*	*Total*
Accepting Errors	Continue using, troubleshoot device	125	161
	Understand imperfections in device	24	
	Positive emotion (e.g., amusement)	12	
Disregarding Errors	Temporarily put away device	40	98
	Hope device will improve in future	44	
	Neutral emotion (e.g., indifference)	14	
Not Accepting Errors	Unwilling to use device in future	14	132
	Hesitant to use device in future	13	
	Feeling device is unreliable	15	
	Negative emotion (e.g., frustration)	90	
Unlikely Situation	Feel unlikely to end up in the situation	32	32
Using Non-Technical Navigation Techniques	Use residual vision, mobility skills	194	463
	Ask someone for help	269	
Social Factors	Social concerns and stigma	43	43

Table 3. High level thematic categories and their associated qualitative codes. Count refers to the number of mentions for each individual code.

Focus Group Participants

We recruited 16 focus group participants (seven female, seven male, two prefer not to disclose). Participant ages ranged from 10-21 (avg. 17). All 16 participants had also completed our survey. We refer to focus group participants as “FG01” to “FG16.”

Focus Group Procedure

We conducted both focus groups on-site at the summer camp. Three researchers were present during focus group sessions. Both focus groups were audio and video recorded and supplemented by field notes. Each focus group lasted approximately 75 minutes. Both focus groups were conducted at the end of the summer camp experience, giving participants time to develop a rapport with one another, which supports openness and sharing in discussion.

Focus Group Analysis

Video recordings of focus groups were fully transcribed. Participant responses were organized into high level categories consistent with our survey codes. Focus group discussions inspired three new codes including "Use residual vision or mobility skills to find destination," "Ask someone for help," and "Social concerns and stigma" (Table 3). We then reviewed our survey responses and updated the code counts. In the next section, we present findings organized by our high level thematic categories and supplemented with Likert and focus group data.

FINDINGS

Many Errors Are Acceptable

We found not only that device errors were sometimes acceptable, but also that errors were accepted as often as they were not. Likert ratings show this trend well, with 41% of all responses falling in the 1-3 range (unlikely to use the device) and 42% falling in the 5-7 range (likely to use the device) (Figure 1, Table 4). These figures are reinforced through our qualitative analysis of open-ended responses, which resulted in three relevant high-level categories: Accepting, Not Accepting, and Disregarding Errors.

Likert Rating	*Accepting Errors (161)*	*Disregarding Errors (98)*	*Not Accepting Errors (132)*
1	6.21%	9.18%	18.94%
2	4.35%	6.12%	18.94%
3	15.53%	11.22%	19.70%
4	25.47%	17.35%	19.70%
5	22.98%	13.27%	10.61%
6	15.53%	21.43%	6.06%
7	9.94%	21.43%	6.06%

Table 4. Correspondence of Likert ratings to open-ended survey responses. Likert responses indicate willingness to continue using the device and range from 1 (“not at all likely”) to 7 (“definitely”). Qualitative responses were organized into “accepting”, “disregarding”, and “not accepting” categories. Scenarios whose responses were coded as accepting were often accompanied by a Likert rating between 5-7. Scenarios whose responses were coded as not accepting were often accompanied by a rating between 1-3.

Table 4 shows there were comparable numbers of mentions indicating accepting (161 mentions) as opposed to not accepting (132 mentions) attitudes toward the device. In the sections below, we present qualitative data that define and exemplify the meaning of these three categories.

Accepting Errors

The Accepting Errors category consisted of responses indicating that participants would continue engaging with the device, would be understanding of the imperfections of technology, or would display a positive emotional reaction in spite of the device's error. Some participants indicated that they would attempt to troubleshoot the device's error (125 mentions), such as when the device failed to identify the room's door:

> *"I would get to a safe spot, out of the way and try restarting the device or turning it off, waiting a few seconds, and then turning it back on again..."-P17 (Scenario 5)*

We categorized troubleshooting as a form of acceptance because it indicates an intention to continue use.

Some participants expressed acceptance of imperfections in technology (24 mentions):

> *"I do understand that technology isn't perfect, I would then attempt to troubleshoot the technology that I am using so that I would be able to find the specific store that I was looking for… sometimes that happens… it's all right, nothing to get worked up about." -P38 (Scenario 9)*

This response to when the device misses a gift shop's logo suggests not only that some technology errors are acceptable, but also that errors do not have to be negatively interpreted. Several responses from participants, showed positive reactions to technical errors:

> *"…I would simply laugh, about it with my friend, who hopefully could also relax and see the humor, and we would simply switch the restroom we each enter." -P19 (Scenario 7)*

Others expressed that they would "laugh" or be "glad" that the error was easy to recover from. Positive responses were not common (12 mentions), but indicate that users may be able to find the silver lining when their device errs.

Not Accepting Errors

The Not Accepting Errors category consisted of responses where participants described disengagement with the device in various forms. This included comments about the device's unreliability and being hesitant to use the device in the future, as well as negative expressions of anger, frustration, and embarrassment.

Most non-acceptance responses involved the user immediately shutting off the device or putting it away. Some participants said they might troubleshoot the device later (as opposed to immediately), or even "go get it checked out" by a third party, suggesting the error might be severe enough to consider the device broken. Other responses indicated a more permanent sense of disengagement. We classified these as hesitant or unwilling to use the device in the future (27 mentions) and feeling the device is unreliable (15 mentions). In the example below, the device misidentifies the gender of a restroom, eroding user confidence and increasing hesitancy toward future use.

> *"I would reconsider using the device in these situations with harsher consequences for error. I would have less faith in the device's reliability and always double-check signage if/when available." -P37 (Scenario 7)*

Many responses included negative emotional reactions (90 mentions). These ranged in severity from "slightly annoyed" or "bothered" to "frustrated," "exasperated," "highly upset," "mad," and even "horrified." Several participants also expressed embarrassment:

> *"I would be embarrassed. Not only did I walk into the wrong restroom, but I guided my friend to the wrong restroom as well. My attempts to show my independence have failed and they are probably thinking bad thoughts about me… I would be hesitant in continuing to use my device…." -P32 (Scenario 7)"*

We chose to categorize these negative emotional reactions as evidence of not accepting the error because they indicate user dissatisfaction.

Disregarding Errors

Some responses neither indicated acceptance nor non-acceptance. In some situations, participants said they would temporarily turn off or put away the device (40 mentions) and revert to their mobility skills or non-technical aids. Participants expressed hope that the device would improve in the future (44 mentions) without indication of long-term loss of faith in the device's ability to perform accurately. Some participants expressed that they would not be emotionally impacted by the device's failure (14 mentions).

> *"I would just put the device away and ask the strangers for directions or even walk with them if they were going to the escalator. I would not worry about it too much, because I want to enjoy the concert and not be stressed." -P25 (Scenario 6)*

In this example, P25 plans to put the device away and "not worry" about the error. There is no plan to troubleshoot, no concern about device reliability, and no negative emotional reaction, as we saw when errors were either accepted or not accepted. Instead, the error is regarded as a non-issue.

Unlikely Situations

There were a few instances where participants expressed feeling unlikely to end up in the situation described in the scenario (32 mentions).

> *"…I would never, ever rely solely on the device to confirm the restroom. Even when people tell me I'm at the women's restroom, I never set foot in the restroom until I touch the Braille sign." -P36 (Scenario 7)*

Most of these mentions came from nine participants in response to Scenarios 4 and 7; these participants indicated they would never enter a bathroom without confirming the gender by reading the Braille sign at the door.

Acceptance of Errors is Highly Contextual

We found that some elements of context make device errors more acceptable, others less. Participants' reactions varied based on the type of error made, the building feature being located, and the social and environmental settings that defined context of use. Finally, beyond concern for technical aspects of the error, participants were acutely concerned about how *others* would perceive the error.

Effect of Error Type on Acceptance

Table 5 details the distribution of 570 Likert ratings across different error types. We found two subtle trends, highlighted in Table 6. First, more participants said they would continue using the device after false negative errors (43%), as opposed to discontinuing use (39%). Second, more participants said they would discontinue using the device after restroom gender misidentification errors (45%) as opposed to continuing use (38%). Qualitative trends found in descriptive responses support and amplify trends in Likert ratings.

Likert Rating	*FN*	*FP*	*MIS*
1	14.47%	13.16%	18.42%
2	12.28%	10.09%	13.16%
3	12.28%	17.11%	13.16%
4	17.54%	16.23%	17.54%
5	16.23%	19.30%	18.42%
6	12.28%	11.84%	5.26%
7	14.91%	12.28%	14.04%

Table 5. Detailed distribution of 570 Likert ratings across FN (n=228), FP (n=228), and MIS (n=114) error types. Median=4.

Likert Rating	*FN*	*FP*	*MIS*
Unlikely to Use (1-3)	39%	43%	**45%**
Neutral (4)	18%	16%	18%
Likely to Use (5-7)	**43%**	40%	38%

Table 6. Aggregated distribution of 570 Likert ratings across FN (n=228), FP (n=228), and MIS (n=114) error types.

Elaborating on our qualitative data, we found that more mentions (77 of 161) indicated acceptance of FN errors than either FP or misidentification errors. In contrast, more participants were *not* accepting of restroom gender misidentification (53 of 132 mentions) than either FN or FP errors. The explanation below illustrates why false positives were infrequently accepted.

"I'm more forgiving of when the device failed to notify me that I reached the intended target. Technology isn't always perfect and I believe there is a big difference between recognizing the wrong thing and failing to recognize something, because it may look different from most things." -P40 (Scenario 3)

Effect of Building Feature on Acceptance

Table 7 details the distribution of 570 Likert ratings across different features. There were two subtle trends we would like to call attention to (Table 8). More participants said they would continue using the device after a device error related to identifying doors (45%), as opposed to discontinuing use (38%). In addition, more participants said they would discontinue using the device after restroom misidentification errors (45%), as opposed to discontinuing use (37%). Analysis of qualitative responses also revealed that error acceptance was contingent on building feature. We found that participants were more accepting of device errors related to doors (49 of 161 mentions). In contrast, participants were mostly not accepting of errors related to restrooms (55 of 132 mentions).

Likert Rating	*Door*	*Logo*	*Stairs/ Escalator*	*Restroom*
1	14.62%	16.67%	10.53%	16.37%
2	9.94%	12.28%	10.53%	13.45%
3	13.45%	10.53%	18.2%	15.20%
4	16.96%	15.79%	17.54%	17.54%
5	20.47%	16.67%	16.37%	17.54%
6	9.36%	14.04%	8.77%	12.28%
7	15.20%	14.04%	12.28%	13.16%

Table 7. Detailed distribution of 570 Likert ratings (likelihood of using the device) across doors (n=171), logos (n=114), stairs/escalators (n=171), and restrooms (n=114). Median = 4.

Likert Rating	*Door*	*Logo*	*Stair/ Escalator*	*Restroom*
Unlikely to Use (1-3)	38%	39%	39%	**45%**
Neutral (4)	17%	16%	18%	18%
Likely to Use (5-7)	**45%**	45%	43%	37%

Table 8. Aggregated distribution of 570 Likert ratings across door (n=171), logo (n=114), stairs/escalator (n=171), and restroom (n=114) building features.

Effect of Environmental Settings on Acceptance

More participants mentioned acceptance of technology imperfections in response to device failures in dense and/or unfamiliar locations (17 and 15 out of 24 mentions respectively) than other contextual extremes. We discovered a possible explanation for this in focus group discussions. Participants expressed a preference to rely on the device in either very crowded or deserted areas. In these particular extreme situations, they found it hard to rely on assistance from passersby because it would be difficult to get their attention. Users may be more likely to continue engaging with a device that has made an error in this situation because there are fewer sources of assistance.

> *"It's probably the fact that when you're in a crowded area, those people tend to ignore everyone around them so when you want to get help, they just ignore you, they won't help you. ... Most of the time they'll just pass you by without realizing it.… but other than that, troubleshooting is probably for when you have no one or nothing around you to tell you where you are and you need to know where to go so that's when you try to double check and triple check the machine." -FG02*

Effect of Social Settings on Acceptance

Participant reactions also varied in response to the social setting parameters in our scenarios—professional vs. personal, and strangers vs. family/friends. Across the 90 mentions of negative emotional responses to errors, 56 mentions occurred in professional situations. Participants explained that in personal settings they would not worry about others' judgments if mistakes occurred. However, in more professional settings appearing competent or professional is of high concern.

> *"I think if you were with friends or family, people that you were really close with, ...I'd be fine with using this technology because if there are mistakes you know people will get it, they won't judge. I think if you were in more of a place with people you don't know or people who you are more conscious about the impression that you have on them, like school or like working somewhere as a profession, or on a date. You don't want to embarrass yourself…." -FG11*

This suggests that errors made by the device can be interpreted by outsiders as errors made by the user.

Acceptable Technical Errors Can Have Unacceptable Social Consequences

The Role of Errors in Perpetuating Stigma

One of the contextual parameters in scenarios was whether or not the device's error was noticed by others in addition to the user. We found that in such scenarios, participants showed signs of concern about social stigmatization in their responses. There were 43 mentions in which participants expressed awareness of onlookers or felt the need to explain the device's error to others.

> *"I'd have less faith in the device's reliability/practical usefulness. The fact that it is a separate device needing to be conspicuously worn would become increasingly bothersome due the its unreliable nature." -P37 (Scenario 2)*

Here, P37 articulates how device errors interact with the fact that the device is conspicuous; an error-prone navigation aid amplifies the signal of disability to others and raises concern for the user.

> *"In this situation, I would be a little frazzled. Since I am in a large room with lots of people, I would rely on my device to assist me in getting where I need to go. Walking around searching for a door would call attention to myself and be somewhat of a distraction to others. I would explain to the attendee that I was trying to exit the room, but my device is not properly reading my surrounds. I would then ask that individual to assist me to the door so that I can leave to make my phone call. After this, I would be somewhat hesitant to use my device." -P32 (Scenario 5)*

Here, we see that P32 is concerned about the social costs of the device not working properly, and that this would negatively impact her trust in the device. While most mentions (33 of 43) were related to whether others noticed the error, 10 mentions cited social concerns even if the participant was the only one who noticed the error.

> *"I would feel awkward, even if I was the only one who had noticed…." -P29 (Scenario 10)*

The Role of Errors in Projecting Disability

Survey and focus group participants explained that their social concerns stem from misunderstandings of passersby about their ability. Several survey participants stated that they would tell passersby that they did *not* need any help. If they did want to ask for assistance, they felt it necessary to specify exactly what they needed so that strangers had less opportunity to make unwanted attempts at assistance:

> *"Instead of someone grabbing my arm, I would just ask them for directions." -P56 (Scenario 5)*

Many participants had previously experienced that after asking a navigation question, passersby would rudely grab their canes or their arms and try to drag them to the destination.

The Role of the Environmental Setting in Disabling Users

Of the 43 mentions regarding social concerns, 30 specifically mentioned dense locations and 27 mentioned unfamiliar ones (not mutually exclusive).

Social concerns were prevalent in scenarios where false negative errors occurred (22 of 43 mentions) and when the errors related to identifying doors (21 out of 43 mentions). This finding is surprising because participants were slightly more accepting of false negative errors (Table 6) and errors identifying doors (Table 8). The conflict suggests that participants were accepting of these errors from a technical standpoint while simultaneously showing concern about potential negative social outcomes.

Making Errors in front of Strangers

More mentions reported concern about social stigma in the presence of strangers (29 mentions out of 43) than friends and family members (14 mentions). Our focus group participants revealed that strangers may believe that blind individuals who use guide dogs are more capable of navigating independently as compared to those who use white canes. This supports findings from [34].

> *"... my friends that have guide dogs... people tend not to do that [grab and pull] as much and treat them more like normal people. With us, with me and other people who use a white cane, they treat us more like we're incapable and like we can't do it." -FG08*

This raises questions as to whether various types of technological assistive devices similarly project more or less ability onto their users. Our survey has revealed that people with vision impairments anticipate that errors made by technical navigation aids may perpetuate negative stereotypes about disability and create opportunities for demeaning social interactions.

Recovering from Device Errors

Many participants identified strategies they would use to recover from device failures. These took two different forms: asking for assistance, and falling back to their own mobility skills.

Asking for Help or Assistance

Participants indicated in nearly half of the responses (269) that they would ask for or accept assistance when the device failed. The majority of requests for help were in reaction to scenarios where someone else noticed the device error (165 mentions). However, there were instances where focus group participants shared that they would avoid asking for assistance, even if approached. These instances included situations where participants were unable to complete the navigation goal and did not want to appear disabled.

Fallback to Mobility Skills

In 194 responses, participants indicated that they would take advantage of their own orientation and mobility skills to get through the situation. For example, some participants stated that they would ask passersby to confirm whether the device was correct that they reached their destination. This implies that blind individuals do not necessarily depend on one single solution to fulfill their various navigation needs.

> *"I would go into each store and ask which store it is. I would ask for verbal directions a few times as I pass, since some people may not know where it is, or may not direct me fine. Once I arrived to where I was directed, I would clarify whether or not it is the correct store." -P47 (Scenario 9)*

Some participants indicated that they would rely on their mobility skills when errors related to store logos (29 mentions) or stairs/escalators (24 mentions). Comparatively more participants indicated that they would rely on their mobility skills when the device did not identify the restroom (74 mentions) or doors (67 mentions) correctly.

More mentions reported relying on mobility skills in professional settings (104 mentions) than in personal settings (90 mentions).

> *"I would be very frustrated because I am trying to make a good impression on my first day. ... I would work extra hard to memorize the area quickly so I could try to prevent this from happening again." -P25 (Scenario 3)*

Reliance on mobility skills instead of an imperfect technology may be explained by wanting to appear competent and independent in front of colleagues. This may reinforce our finding that participants were less accepting of errors in professional settings.

DISCUSSION AND IMPLICATIONS FOR DESIGN

Users Accept Errors, Designers Should Too (in some contexts)

We found that not all errors made by imperfect technology are necessarily problematic. We further found that error acceptance varied based upon aspects of the context; error type, device feature, environmental setting, and social setting all had bearing.

False negative errors were seen as more acceptable, whereas misidentification of bathroom gender was not. Failure to locate doors was seen as low-stakes, so related errors were more accepted. Finally, professional or unfamiliar settings in the presence of strangers made errors much less acceptable than those that took place in personal or familiar settings in the presence of family and friends. This suggests that errors may have varying levels of cost associated with them (often social).

While errors made by technology may be acceptable, designers should pay close attention to which types and contexts of errors should be avoided and which are less concerning. In other words, not all errors are created equal, and through error-conscious design, technologies with imperfect accuracy may still be acceptable and adoptable. Seeking an error-free device as opposed to a device with appropriate error types and rates may not be the most effective approach to achieve technology adoption or usability for target users.

Users Accept Errors, Designers Should Not (without further investigation)

The quantitative Likert ratings and qualitative responses both strongly indicate that participants found certain errors acceptable. Deeper qualitative interpretation and focus group follow-ups revealed that these same error scenarios pose social challenges as a direct result. For example, participants were generally accepting of technical errors made in identifying doors because these are possible to find using complementary non-technical navigation techniques. But, participants also voiced concern that onlookers might mistake the device failure as an invitation to interfere in various unwanted and demeaning ways—by grabbing their arm or their white cane, for example. This mirrors findings from Shinohara and Wobbrock [29] that assistive technologies, particularly those that are conspicuous, can be sources of stigmatization and reduce device adoption.

One implication of our findings is that designers cannot simply stop at understanding single-user error acceptance; subsequent social interactions are critical, particularly when designing for historically marginalized, misunderstood, minority populations. Designers therefore need to investigate what happens *after* device errors are made with attention to the behavior of *others*. Any instruments used to study acceptance of errors would need to accommodate feedback about second-order effects. Otherwise, error-prone technologies may ultimately perpetuate existing stereotypes and leave users vulnerable to socially unacceptable interactions with collocated sighted strangers

Design for Context-Aware Error Tolerance

In light of the finding that specific elements of context influence error acceptance, designers should shift focus from merely designing for error-free technologies towards designing for appropriate errors in context.

Computer vision algorithms, for example, need adjustment and targeted training in order to recognize a specific object within a certain accuracy threshold. Designers can prioritize where their time and resources will be best spent if they understand the environments and contexts in which their technology will be used. Designers who understand context may find that not all features are worth the investment.

Moreover, some systems may benefit from real-time, context-aware adjustments to error-tolerance. For example, when the user is in a crowded environment, the device might automatically increase its threshold for tolerating false negative errors. This might increase the number of correct (and incorrect) building feature identifications without risking user disengagement. This type of real-time strategy may be particularly useful in the domain of mobility aids because users may transition through many environments while using technology throughout the day.

Design for User-Preferred Error Tolerance

Following from the point above, and because context-aware applications are known to have limitations [10], we additionally recommend that users be given more explicit control over the errors their devices make.

When computer-vision algorithms are tuned to make fewer false negatives, the risk of making false positives increases and vice versa. Context of use can change over time. Designers can account for this by allowing users to customize their device by selecting their preferred error type depending on the current situation.

Designers, for example, might incorporate preference panes so that users can play an active role in configuring the technology to trend toward certain error types over others (e.g., preferring false positives in professional settings to false negatives). Alternatively, the interface might notify users of how confident the algorithm is that its current reading is accurate. This would allow users to make judgment calls about whether the device should be relied upon given the setting. We can imagine that supporting this type of active error management may lend participants a heightened sense of control in situations where they feel vulnerable to unwanted “assistance” from well-intentioned but very misguided passersby.

LIMITATIONS AND FUTURE WORK

We used a survey to assess user responses to errors made by a hypothetical technology. This removed the burden of traveling to one or more study sites for users, allowing us to gather data from a large population and consider a wide variety of use case scenarios. However, a limitation of this decision is that our participants did not interact with a functional system. To increase confidence in our findings, we conducted focus groups to provide user perspectives on errors made by navigation technologies they have used. While we are unable to fully represent our rich qualitative focus group data in this work, we feel confident that our scenarios were relevant to our users. Only 32 mentions out of 570 indicated that a participant felt unlikely to end up in a scenario described in our study. We look forward to future work that compares our survey findings to findings from users interacting with navigation technologies.

CONCLUSION

We examined how user perception of device errors affects adoption of an indoor navigation aid. Through a survey and follow-up focus groups, we investigated how users react to errors commonly made by computer vision technologies across scenarios of use. Our findings revealed that users are accepting of errors in many situations, depending on the context. At the same time, we found that errors may stigmatize users by drawing undue attention from bystanders. We suggest that recognition technologies that make errors can still be adopted if designed to be error-conscious, context-aware, and configurable.

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