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Navigational Aid Use by Individuals with Visual Impairments

Zeynep Başgöze[1], Justin Gualtieri[2], Madi T. Sachs[1], and Emily A. Cooper[1]

[1]School of Optometry & Vision Science Program, University of California, Berkeley, CA

[2]Department of Computer Science, Dartmouth College, Hanover, NH

bagze001@umn.edu; justin.d.gualtieri.18@dartmouth.edu; mts@berkeley.edu, emilycooper@berkeley.edu

Abstract

Navigation is a multifaceted task, which requires using a combination of strategies and cues from the environment. Navigation can be particularly challenging for individuals with impaired vision, because many informative cues are visual. As mobile computing technology rapidly advances, the range of potential approaches to assist visually impaired people with navigation is also broadening. For computer-based navigational aids, the way in which information is gathered, processed, and presented is key to success and represents a vast space of potential approaches. In an effort to improve understanding and provide guidance on this issue, we present the results of a phone survey about navigational aids from a sample of individuals with impaired vision. The survey assessed the usefulness of existing navigational aids (both low-tech and high-tech) for different aspects of navigation. With an emphasis on indoor wayfinding (orienting oneself and following a route in a building), we also collected responses about specific targets the survey participants search for while navigating, and strategies they commonly use. Our results indicate that indoor wayfinding is a relatively under-supported task during navigation despite rapid advances in technology. These results also provide insights for creating navigational aids that are designed more specifically for the current challenges individuals with impaired vision may experience during this task.

Keywords

Visual impairment, assistive technology, navigation, indoor wayfinding

Introduction

A range of low-tech assistive tools are available to support navigation with impaired vision (e.g., mobility canes, guide dogs, optical devices). However, some individuals with impaired vision may restrict their independent travel in daily life (Wang et al.; Rudman and Durdle). In recent decades, researchers and engineers have been working to harness advances in mobile computing to improve and broaden navigational aids (Hakobyan et al.; Giudice and Legge). To guide the design of new and effective assistive technologies for navigation, a systematic – and current – understanding of the challenges faced by navigators with impaired vision is essential.

Prior research has provided insights into the experience of navigating with impaired vision using a variety of approaches. Studies based on quality-of-life questionnaires indicate that people with impaired vision experience a range of challenges with independent navigation, such as detecting obstacles and judging distances (Stelmack and Massof; Stelmack et al.; Nelson et al.; Massof). At the same time, laboratory mobility studies provide useful insights into how different levels of visual impairment impact navigation in a controlled setting, for example, suggesting that reduced peripheral vision and contrast sensitivity are most predictive of obstacle collisions (Black et al.; Marron and Bailey). However, these studies are not designed to directly assess the strategies and tools that an individual with impaired vision uses and needs for independent navigation. To address this gap, contextual inquiry studies have been conducted in which researchers observe people during natural tasks and conduct interviews. These studies suggest that the usefulness of high-tech navigational aids (e.g., mobile device applications) is highly task-specific (Szpiro et al.; Zhao et al.). Importantly, it is often noted in the research literature that indoor wayfinding (i.e., orienting oneself and following a route in a building) is relatively unsupported by current navigational aids (e.g., Szpiro et al.; Legge et al.; Huang et al.; Ahmetovic et al.; Tian et al.; Coughlan and Manduchi; Liu et al.).

Even if the lack of tools that support indoor wayfinding is widely acknowledged, it is still not clear what the best approach is for designing new navigational aids that support this task. For an individual with impaired vision to successfully find their way indoors, gathering information from the environment is of course necessary, but might not be sufficient. The way in which information is processed and presented is key to success, and it is unclear what the best approaches may be. Researchers have started to examine this specific question by surveying visually impaired people about how they use currently available assistive technology (Goldberg et al.). Questions that can help inform this issue further include: what tools and strategies do individuals with impaired vision currently use for navigating through different environments, and how useful are these existing tools and strategies? What common features or landmarks in the environment are the most difficult to locate while navigating indoors? In an effort to broaden understanding of these issues, we present the results of a phone survey about navigational aids from a sample of individuals with impaired vision, with a particular focus on indoor wayfinding.

The primary contributions of the current work are:

(a) An examination of how useful people with impaired vision tend to find current low- and high-tech navigational aids for different aspects of navigation. The results suggest that existing high-tech tools are not commonly found useful for indoor wayfinding, although low-tech aids are providing some support for this task.

(b) An examination of the strategies that some individuals with impaired vision currently use to support their indoor wayfinding needs, as well as the specific targets they find most challenging to locate. The results suggest that restrooms, signage, and stairs/elevators represent relatively common targets of search, and that currently people may often ask somebody for help to find these targets in lieu of using a navigational aid. This is likely because existing tools do not provide sufficient support for locating these targets.

Methods

Twenty-one adults with impaired vision (9 females and 12 males, aged 25-70 years) were recruited for a phone survey via email advertisement. Participants self-reported a range of acuity levels: better than or equal to 20/200 (n = 6), less than 20/200 (n = 9), and light perception (n = 6). Twelve participants reported having reduced peripheral visual field. The two most common causes of visual impairment were retinitis pigmentosa (24%) and glaucoma (19%). The duration of impairment ranged from 1 year to 64 years. The participants had a range of education levels: as their highest degree, 57% had a master's/professional degree, 29% had a bachelor's/associate degree, and 14% had a high school diploma. When asked about levels of daily activity, with 1 corresponding to sedentary and 5 corresponding to highly active, all rated their activity level as 3 or higher. To quantify participants' general ability to self-locate and perform wayfinding, we also administered the Santa Barbara Sense of Direction Scale, a standardized 15-item questionnaire (Hegarty et al.). The average participant score on this scale was 4.6 (standard deviation 0.8) on a 1-7 scale, which is typical of the scores reported for typically-sighted populations.

The phone survey consisted of close-ended (yes/no, frequency, and Likert scale) and open-ended questions about navigation and navigational aids, with an emphasis on indoor wayfinding. Prior to finalizing the survey focus and content, four pilot participants were recruited to complete the survey and provided feedback. All participants were compensated, and the procedures were approved by the Dartmouth College institutional review board.

Non-parametric tests for statistical significance were used to analyze the data. Friedman tests were used to determine statistically significant differences in Likert ratings between questions ($p < 0.05$ significance threshold). For cases in which more than two questions were compared, follow up Wilcoxon signed rank tests were used to determine which pairwise comparisons were statistically significant. Exploratory analyses were conducted to examine differences in responses based on individual characteristics (e.g., level of vision, age, impairment duration), but no significant relationships were identified. It is important to note that the current study sample size was not designed to examine individual differences, so these analyses are not reported. Finally, for the open-ended questions, some raw responses were re-coded to capture common trends (e.g., responses of ‘corridors’ and ‘hallways’ were both coded as hallways).

Results and Discussion

All participants had some functional vision, so before examining the use of different navigational aids, we wanted to summarize how useful the participants find their own vision while navigating. We focused on three basic navigation tasks: 1) avoiding running into things (obstacle avoidance), 2) finding one’s way or orienting *outdoors* (outdoor wayfinding), 3) finding one’s way or orienting *indoors* (indoor wayfinding). Usefulness ratings were collected on a scale of 1 to 5, with 1 being extremely useful and 5 being not useful at all. The median ratings for usefulness of vision for obstacle avoidance, outdoor wayfinding, and indoor wayfinding were 3, 3, and 2, respectively. While vision was descriptively rated as more useful during indoor wayfinding, a Friedman test showed no significant differences for these tasks ($Q = 5.64$, $p = 0.06$). In a follow up question, participants indicated that their vision was more useful for wayfinding in familiar indoor environments (median = 2) than in unfamiliar indoor environments (median = 3, $W = 146$, $p = 0.007$).

Despite finding their vision useful for a range of navigation tasks, many people with impaired vision also make use of navigational aids. In our survey, all of the participants indicated using some form of navigational aid. We focus first on *low-tech* aids. In our survey, these included mobility canes and guide dogs. While optical devices may also be used during navigation (e.g. a monocular telescope), we did not examine usage of these devices in the current survey.

The most commonly reported low-tech aid was the mobility cane (90%), and most participants reported using a cane daily or weekly (81%) (Figure 1, left panel). Using the same scale described above (1 being extremely useful and 5 being not useful at all) we asked participants to rate the cane. Descriptively, users rated the cane as most useful to avoid running into things (median = 1), but it was also rated as being useful for wayfinding tasks both outdoors (median = 2) and indoors (median = 3) (Figure 2, left panel). A Friedman test showed a significant difference between ratings on these tasks ($Q = 8.39$, $p = 0.02$). Follow up Wilcoxon signed rank tests showed that the cane was rated more useful for obstacle avoidance as compared to both outdoor ($W = 59$, $p = 0.02$) and indoor wayfinding ($W = 77.5$, $p = 0.02$), but there was no significant difference between ratings for outdoor and indoor wayfinding ($W = 20$, $p = 0.88$).

Despite the cane being clearly most useful for obstacle avoidance, the median cane ratings for wayfinding were well above the bottom of the scale. While the cane may not be conventionally considered a wayfinding aid, it is notable that people also find it useful for wayfinding in a variety of environments. Combined with orientation and mobility training, people may learn to obtain key wayfinding cues using a cane, for example, via identification of curbs and ground texture changes. Not surprisingly, more experienced cane users also reported finding it more useful. A Spearman correlation analysis demonstrated that greater frequency of cane use was significantly correlated with rating the cane more useful for obstacle avoidance ($r = 0.61$, $p = 0.01$) and outdoor wayfinding ($r = 0.54$, $p = 0.02$), but the correlation with indoor wayfinding did not reach statistical significance ($r = 0.36$, $p = 0.13$).

With respect to other low-tech navigational aids, two participants in our sample reported having a guide dog (which supported them daily). Both participants rated the dog at the top of the usefulness scale for all aspects of navigation. One participant rated the usefulness of the guide dog as 1 (most useful) for all tasks, and the other participant rated their dog as 1 for avoiding obstacles, and as 2 for outdoor and indoor wayfinding.

In summary, our results for low-tech navigational aids suggest that these aids represent versatile tools that provide support across a range of navigational tasks in daily life. However, there is a large amount of navigational information that is not made accessible by these aids (e.g. written signage, long-range route guidance). Additionally, guide dogs come with other responsibilities that may not be desirable for everyone. For these reasons, researchers have worked to develop a next generation of high-tech navigational aids based on mobile computing.

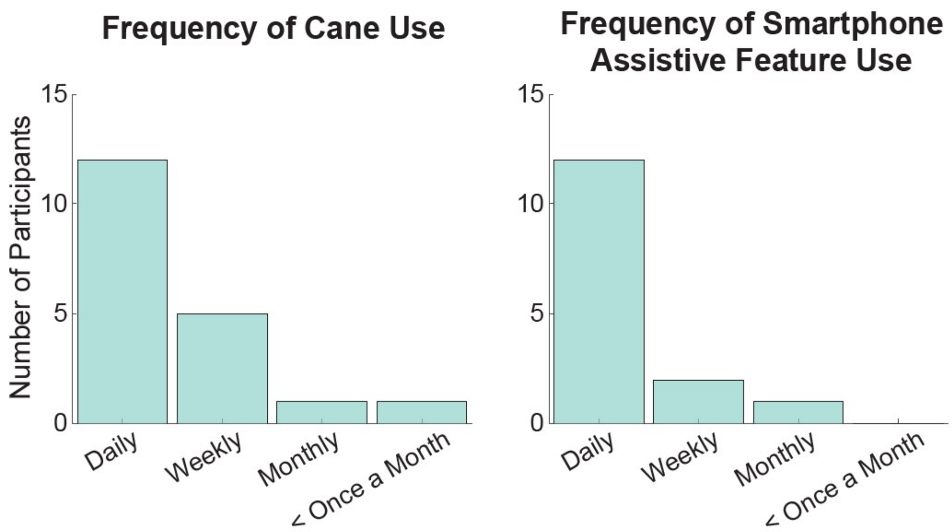

Fig. 1. Histograms indicating frequency of use for canes and smartphones.

Next, we focus on the results for the *high-tech* navigational aids. When asked about mobile computing devices, 76% of participants indicated that they own or use one. Most of these participants had smartphones (fourteen owned Apple iPhones and two owned Samsung phones) and reported using the assistive features of the phones (including downloaded apps) daily or weekly (67%) (Figure 1, right panel). How helpful are these currently available features for navigation? Unlike the cane and guide dog, smartphones were only rated highly useful for outdoor wayfinding (median = 2) and tended to be rated at the bottom of the scale for the other two queries: obstacle avoidance (median = 5) and indoor wayfinding (median = 5) (Figure 2, right panel). A Friedman test showed a significant difference between ratings on these tasks (Q = 24.33, $p < 0.001$). Follow up Wilcoxon signed rank tests showed that the smartphone was rated as more useful for outdoor wayfinding than indoor wayfinding (W = 105, $p < 0.001$) and obstacle avoidance (W = 78, $p < 0.001$), but there was no significant difference between indoor wayfinding and obstacle avoidance (W = 0, p = 0.25). The likely explanation for this finding is that GPS-related technology on smartphones has proven useful for navigating outdoors, but the on-going development of other forms of navigational assistance has yet to be implemented in a wide-spread, accessible manner on consumer mobile devices. Not surprisingly, more experienced smartphone users reported finding these devices more useful for outdoor wayfinding tasks only. Specifically, a Spearman correlation analysis demonstrated that the frequency of smartphone use was significantly correlated with rating the smartphone more useful for outdoor wayfinding ($r = 0.56$, $p = 0.03$), and not for the other two navigation tasks (obstacle avoidance $r = 0.30$, $p = 0.28$; indoor wayfinding $r = 0.30$, $p = 0.28$). Amongst the survey participants, there was only one smart watch user, and they indicated that they did not find the device useful during navigation.

In addition to consumer smartphones, there are a range of electronic travel aids (ETAs) designed for individuals who are blind or visually impaired. With respect to ETAs, two participants in our survey reported using a Victor Trek (*humanware.com*) and were divided on whether it was useful for obstacle avoidance and outdoor wayfinding (one participant rated these two aspects as 2; whereas the other participant rated both as 5 (least useful)). Notably, they both agreed it was not useful for indoor wayfinding (both rated as 5).

In summary, as compared to the low-tech aids, the high-tech aids used by the participants were relatively limited to being useful for outdoor wayfinding.

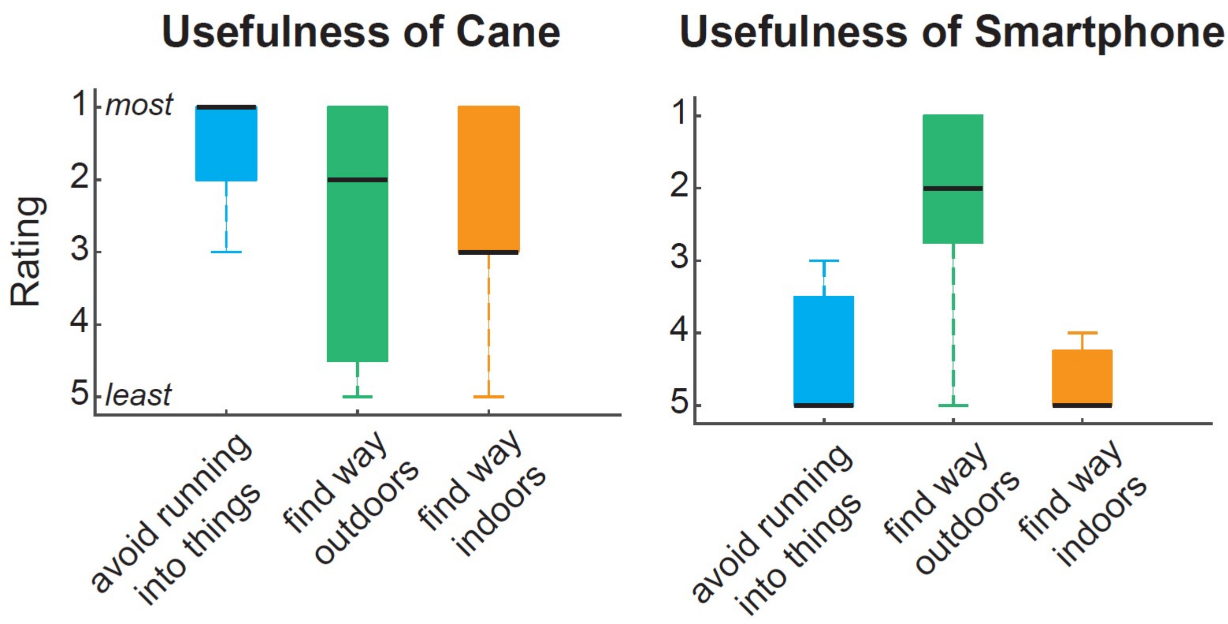

Fig. 2. Usefulness ratings for three navigational tasks for canes and smartphones. In each box plot, the black line indicates the median, the box represents the interquartile range, and the dashed lines indicate the span of non-outlier responses.

Thus far, the current survey results support the research consensus that indoor wayfinding is relatively under-supported by navigational aids compared to outdoor wayfinding, particularly for high-tech aids. While mobility canes may provide some useful information for wayfinding, they are not appropriate for tasks like long-range route guidance or identification of many types of environmental wayfinding cues (e.g., signs, kiosks). The research literature offers many examples of promising high-tech indoor wayfinding assistance systems (Legge et al.; Ahmetovic et al.; Fallah et al.; Zhang et al.; Kim et al.; Asad and Ikram; Alghamdi et al.; Tian et al.); but based on our survey results these types of approaches do not yet appear to be impacting day-to-day navigation. If a high percentage of people with impaired vision already use mobile devices, these multi-use platforms represent a potential route to fill the indoor wayfinding gap. However, this potential does not appear to have been realized yet.

One issue is that indoor wayfinding represents a complex perceptual and cognitive task with limited non-visual infrastructure (unlike GPS infrastructure for outdoor wayfinding). Moving forward, computer vision-based wayfinding aids may be able to assist with identifying environmental cues, but determining which cues are informative and how to filter and convey this information is a non-trivial task. Beacon-based systems may be used to tag important locations and landmarks, which can then be detected by a mobile sensor, but how to effectively guide individuals to these targets while avoiding obstacles and traversing different building layouts remains an open question.

Because the implementation details of a high-tech indoor wayfinding aid are complex, it is essential to focus on the specific approaches and challenges that can have maximum impact on supporting daily navigational tasks of this nature. Thus, we asked the survey participants two open-ended questions about indoor wayfinding in their daily lives. First, we asked participants about what strategies they currently adopt for this task (Table 1). The results were overall consistent with the close-ended survey questions. For example, only one participant reported using their mobile phone, whereas five reported using their cane and two reported using their dog. Despite using these tools, the most commonly reported strategy was to ask someone for help (67%). Other approaches included cognitive strategies such as advance preparation and mental mapping. Regardless of the platform, existing navigational aids are likely still less efficient than human help and well-executed advance planning. This observation suggests that designers and engineers might be inspired by human-to-human interactions (e.g., verbal communication, question/answer format) when considering approaches to delivering wayfinding information. Indeed, smartphone apps are currently available that link a visually impaired user with a remote typically-sighted volunteer or agent via a camera feed such as

Be My Eyes (bemyeyes.com) and Aira (aira.io), and a recent report described the design of an assistive device that gives simulated 'voices' to objects in the environment (Liu et al.).

Table 1. Percentage of responses for strategies used to locate objects/places in unfamiliar buildings.

Indoor Wayfinding Strategies	**# of participants**	**%**
Ask someone	14	67
Use cane	5	24
Sound or touch	4	19
Advance preparation	2	10
Remember location	2	10
Use guide dog	2	10
Use landmarks	2	10
Always go with family member	1	5
Applications on phone	1	5
Break things into grids	1	5
Finding intersections	1	5
Look for doors	1	5
Mental mapping	1	5
Search with vision	1	5
Signage	1	5
Trace walls	1	5
Try to find map kiosk	1	5

Finally, we also asked participants about things that they look for but have trouble finding in unfamiliar buildings. This question revealed several common targets of search (Table 2). Most notably, 43% of respondents reported often experiencing difficulty searching for the restroom in unfamiliar buildings. Other targets that were reported as being hard to locate were signage/text (33%), stairs/elevators (33%), and information kiosks (19%). Providing directed guidance towards common targets such as these may facilitate the impact of mobile computing on navigation. For example, computer vision-based systems could be trained to identify these targets specifically, rather than rely on more general-purpose object detection algorithms that may be broader but less reliable at detecting targets that are high priority. Restrooms in particular represent a ubiquitous feature of both public and private indoor spaces, which might feasibly be located with a combination of computer vision and infrastructure knowledge (e.g., building blueprints). Finally, restrooms, stairs, and kiosks may often be indicated with symbolic signage rather than text. These symbols may not typically be integrated in general purpose optical character recognition algorithms, but nonetheless they have common features that make them likely feasible to train a computer vision algorithm to detect, with the appropriate training data.

Table 2. Objects, features, landmarks, or places that are searched for and difficult to identify

Search targets hard to find	**# of participants**	**%**
Restrooms	9	43
Signage/text	7	33
Stairs/elevators	7	33
Navigational/informational kiosks	4	19
Doors/doorways	3	14
Elevator buttons	2	10
Exits	2	10
Hallways	2	10
Restroom layout	2	10
Alternate routes	1	5
Anything outside visual range	1	5
Bus stops	1	5
Colors	1	5
Elevators	1	5
Handicapped access buttons	1	5
Lighting changes	1	5
Maps	1	5
Office locations	1	5
Walls	1	5

Conclusion

The success of a navigator depends on complex interactions between their environment, their perceptual/cognitive/motor capabilities, and the tools at their disposal. As mobile computing technology continues to develop rapidly, we should not consider this a static problem space, but rather an ecosystem that is changing over time. The current survey provides a snapshot of the current status of navigation and navigational aids for a sample of people with impaired vision. An important caveat is that the current participant group was not selected as an unbiased sample. Notably, all participants had computer access and tended to be located in a particular geographic area (the eastern United States). Differences in access to technology and support services likely impact the experience and challenges associated with navigation, and are thus highly relevant to consider when developing tools that will have a broad impact. Furthermore, the current survey did not include questions about low-tech optical devices nor did it include questions about the training experience of the survey participants, such as orientation and mobility training. Nonetheless, common trends and potential priorities emerged from the current data that can provide guidance and be built upon with larger survey samples.

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