User Interface Preferences in the Design of a Camera-Based Navigation and Wayfinding Aid

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Structured abstract: *Introduction:* Development of a sensing device that can provide a sufficient perceptual substrate for persons with visual impairments to orient themselves and travel confidently has been a persistent rehabilitation technology goal, with the user interface posing a significant challenge. In the study presented here, we enlist the advice and ideas of individuals who are blind with respect to this challenge, for an envisioned camera-based aid to navigation and wayfinding. *Methods:* We administered a short questionnaire about user preferences and needs for such a device to a sample of 10 well-educated, employed (or retired) visually impaired participants with light perception or less, who were familiar and comfortable with assistive technology. Generally, the items were rankings of relative priority. *Results:* Participants preferred speech as a communications medium for navigating the environment; preferred controlling the auditory display by querying the system rather than interacting via a menu or receiving a stream of continuous speech; and preferred providing input to the system through a keypad rather than through a voice recognition system. Architectural features such as doors and stairs were ranked the most important environmental objects to be located with such a device (over furniture, persons, personal items, and even text signs). *Discussion:* Our sample reported a desire for devices that can guide them to architectural features of their environment. They appear to prefer device interfaces that give them control, and would rather query a system than interact with a menu. They prefer unobtrusive input on a device via keypad rather than through voice recognition. *Implications for practitioners:* Designers of camera-based navigation devices may wish to consider the preferences of our sample by incorporating a query-based interface with simple keypad input and speech output, and to include in their object recognition efforts the goal of identifying architectural features that are significant to users who are blind in navigation.

Since the advent of digital cameras and other electronic remote sensing devices, there have been scores of attempts to use these technologies to help persons who are blind or have severe low vision navigate and find their way in their environment. Recent surveys of such attempts can be found in Dakopoulos and Bourbakis (2010), Giudice and Legge (2008),

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Manduchi and Coughlan (2012), and Roentgen, Gelderblom, Soede, and de Witte (2008). Each of these surveys has stressed the importance of two central and persistent issues in the design of such systems: how a system can best communicate information required to operate the system (the *user input*), and how the system can best present spatial information nonvisually to the user (the *display* or system output)—together, these comprise the human interface.

Design of an effective user input system is challenged by the increasing complexity of functions that can be performed by the device. A functionally simple device such as an electronic cane, which needs to detect only obstacles, may have an input interface as simple as an on-off switch, whereas a system that can recognize and report the location of a variety of environmental objects and announce wayfinding directions will require a far more complex input interface.

Design of a display (that is, a system output), on the other hand, requires consideration of the limited processing capacity of the (nonvisual) senses. The biological visual system for which an electronic navigation device substitutes normally processes vast amounts of information in parallel, allowing information from widely disparate locations over the visual field to be integrated in support of pattern and object recognition. It further extends the reach of these resources by integrating information across successive eye movements and through attentional mechanisms, which may direct eye movements and allocate resources to selected portions of the visual field. None of the other biological senses have that amount of spatial and temporal capacity.

Two broad classes of display solutions have been applied to cope with limited capacity. One class assigns the difficult pattern and object recognition tasks to the parallel processing capabilities of a different sense modality such as touch or hearing. For example, some systems display imagery on the skin (Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969) or tongue (Bach-y-Rita, Kaczmarek, Tyler, & Garcia-Lara, 1998; Bach-y-Rita & Kercel, 2003; Danilov & Tyler, 2005) via an array of vibrotactile or electrotactile stimulators. Some proposed systems display the imagery as sounds and combinations of sounds (Cronly-Dillon, Persaud, & Gregory, 1999; Meijer, n.d.). The rationale of this class of solution is that the basic sensory architecture of the brain can be recruited to perform the integrative and pattern recognition functions at which it already excels. While such systems generally suffer from poorer and mismatched capabilities of the substitute sense relative to vision, they have the advantage of relatively modest output (nonvisual display) requirements. For example, orientation and approximate size of a recognized shape are potentially instantly recognizable by the user of a tactile array system such as BrainPort (Danilov & Tyler, 2005) or even a sonic system such as the vOICe (Meijer, n.d.), because the recognition itself is performed in a sensory "space" that is analogous to, if not isomorphic with, the two-dimensional retinal image.

The other class of solution for coping with limited processing capacity combines remote sensing by some means such as laser range sensing (Benjamin, Ali, & Schepis, 1973), sonar (Borenstein & Ulrich, 1997; Kay, 1974), or camera imagery, with subsequent electronic processing including computer vision techniques (Tian, Yang, &

Arditi, 2010; Tian, Yi, & Arditi, 2010). Here detection and recognition of objects or obstacles are accomplished by signal- and information-processing capabilities of the device rather than by the user's brain, and are subsequently conveyed to the user by some other means, such as speech, coded vibrotactile messages, or sonification. For simple obstacle detectors, the output (that is, the nonvisual display) of information can be relatively simple. However, for a computer-vision system that may detect and recognize multiple objects in the scene and perform tracking of objects and scene elements, system output to the user is likely to be a significant bottleneck. In this class of system, design of an effective interface for display of information to the user is a significant challenge.

Our own efforts are focused on developing a computer vision-based navigation aid, because we believe this approach holds the greatest long-term promise, given the continually rapid growth in capabilities of computer and robotic technology fields of computer vision and robotics (Bonin-Font, Ortiz, & Oliver, 2008; DeSouza & Kak, 2002). The need for robots to navigate in the environment, in particular, is fueling the development of computer vision techniques for object recognition and scene analysis, along with localization and mapping. Already, computer vision systems can recognize and track human faces, cars, and some other everyday objects, and within just a few years they will be able to perform far more complex recognition tasks. With such capabilities approaching, we have begun to consider how best to design a human interface for blind users of a camera-based navigation and wayfinding aid.

In this study, we assessed preferences and priorities of a sample of participants who were blind pertaining to functional aspects of the interface design of wearable camera-based devices that exploit machine vision techniques for object recognition, navigation, and wayfinding. Our survey is modest in scope, but it produced several interesting results that we hope will be useful to anyone designing such a device.

Methods

PARTICIPANTS

Our general method was to ask individuals who are blind questions about their needs and preferences in the design of a portable camera-based device that might serve as a vision substitute for performing certain tasks that sighted people generally perform visually. We thus selected blind persons whose visual impairment was severe enough that they were likely to benefit from a camera-based navigation and wayfinding device. In determining who was likely to benefit, we presumed that ability to read text of any size might indicate some ability to navigate visually, and so excluded such participants. To ensure that our participants were mobile and ambulatory and to some degree independent travelers, we included only participants whose customary navigation aid was nonhuman, such as a long cane or a dog guide, but excluded those who customarily depended on a sighted guide for most of their travel. The population of people who are blind who have little or no vision that is useful for navigation and wayfinding is small, with only approximately 109,000 long

Table 1
Characteristics of the participants.

Factor	Characteristics
Age	Range 36.4–72.3; median 58.6 years
Visual function status	5 had no visual sensation, 1 could locate bright lights in their environment, 4 could locate large objects visually. All were legally blind; none were able to read text of any point size.
Gender	5 male, 5 female
Race	8 Caucasian, 1 Hispanic, 1 African-American
Recentness of vision loss	Range 8–62 years
Living arrangement	5 with spouse or significant other, 1 with other relative, 4 alone
Primary travel aid	6 white cane, 4 dog guide
Employment status	7 employed, 1 self-employed, 2 retired
Highest education	1 high school, 2 college, 7 graduate degrees
Braille	7 users, 3 nonusers

cane and 7,000 dog guide users in the United States ("Facts and Figures on Adults with Vision Loss—American Foundation for the Blind," n.d.) relative to 1.3 million persons who are legally blind as of 1994, making construction of a sample representative of this population difficult, especially in light of the many potentially relevant stratifications, including socioeconomic status, rural vs. urban and suburban, age, sex, prior visual experience, and employment status. Some characteristics of the participants are shown in Table 1. The sample consisted of adults, mostly middle-aged, who had been visually impaired for most or all of their lives. All used computers equipped with screen readers, with 6 self-identifying as "expert" users and 4 as able "to accomplish their most important tasks with the computer, including e-mail." Of those 10, 2 were assistive technology teachers; 2 had jobs providing assistance to blind and sighted users with computers and technology; and 3 worked in occupations of an advisory nature to other persons with visual impairments that required familiarity with assistive technology.

The sample was thus uncharacteristic of the disabled population at large, which evidences sharp disparities in educational attainment, employment status, and earnings (U.S. Census Bureau, 2010). Our 10 participants were highly educated, employed (or retired), and independent, and had good access to, use of, and comfort with computer technology. As such, one might expect our results to differ somewhat from a survey that cast a broader net. Given our sample's substantial experience with computers, screen readers and other assistive technologies, we believe it is more representative of those who are comfortable with assistive technology than the population of blind people at large, and of those who might be expected to use the envisioned device were there no other barriers such as cost.

INTERVIEWS

The interviews were conducted by one or both authors, via telephone or in person at the City College of New York (CCNY) Media Laboratory, in conjunction with, and always prior to informal observations on how participants aim small cameras to image specific objects (not reported here).

This research followed the tenets of the Declaration of Helsinki. Informed consent was obtained from the participants after verbal explanation of the nature and possible consequences of the study, and the CCNY institutional review board approved the study. Participants were also given copies of informed consent materials in both paper form (for their records) and their choice of accessible format, which in all cases were electronic files. After obtaining screening and background information (see Table 1), subjects were told, "We are interested in developing a portable camera-based device designed for blind users that might serve as a vision substitute for performing certain tasks that most people perform with their eyes." They were then verbally asked general questions focusing on their needs and preferences as blind users. In most of these, they were asked to rank two or more options, ranging from "1" to the total number of options. The number of possible ranks was equal to the number of options, but participants were able to assign the same rank to more than one choice. Participants were encouraged to ask for amplification or clarification as needed.

DATA ANALYSIS

Data were analyzed using nonparametric statistics. Significance for ranked data with two groups was tested with the Wilcoxon rank sum test (also known as the Mann-Whitney U test). Overall significance with more than two groups used the Friedman rank sum test, which may be conveniently considered as a nonparametric alternative to a repeated measures one-way analysis of variance. In the results below, *p*-values are uncorrected for multiple tests.

Results

In the results below, where there are significant differences we show box-and-whisker plots of the distributions of rankings. The bold horizontal line is at the median rank. The box extends to the full interquartile range of the ranks, while the whiskers represent minimum and maximum ranks that are within 1.5 times the interquartile range of each end of the box. The small circles exceed those limits and are considered outliers. The interquartile range (that is, the box) contains 50% of the rankings.

PREFERRED INFORMATION PRESENTATION MEDIUM FOR NAVIGATING IN THE ENVIRONMENT

Participants were asked to rank in order of preference which medium of information display they would prefer for the receipt of information about the environment while navigating, choosing from "refreshable braille"; "speech through open (allowing simultaneous hearing of environmental sounds) headphones"; "a tactile screen displaying tangible raised symbols"; "sound symbols such as beeps, clicks, bells, musical tones also presented through open headphones"; and "a vibrating belt that indicates permissible directions of travel and/or nearby obstacles." Results are shown Figure 1. Of these types of information display for navigating in the environment, speech was the highest or second highest in rank for all 10 subjects ($\chi^2 = 22.17$, df = 4, $p = 0.00$). Braille was significantly chosen as a *least* preferred method (ranking 4 or 5 in preference for 7 of 10 subjects, $\chi^2 = 10$, df = 4, $p = 0.04$). Not surprisingly, all 3 of the participants who were not braille readers were among the 7 who ranked braille as

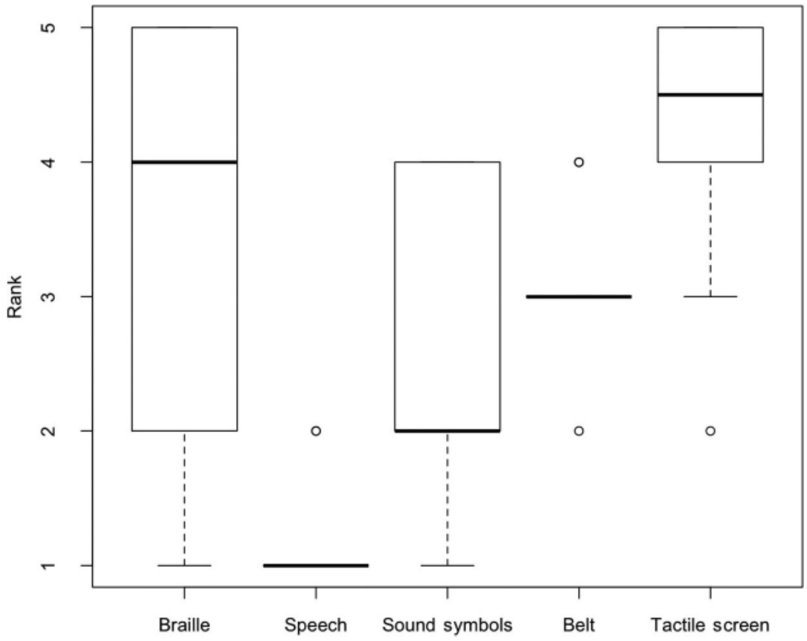

Figure 1. Rankings of preferred presentation medium for navigation through the environment. Lower ranks indicate higher preference. The bold horizontal line is at the median rank. The box extends to the full interquartile range of the ranks, while the whiskers represent minimum and maximum ranks that are within 1.5 times the interquartile range of each end of the box. The small circles exceed those limits and are considered outliers. The interquartile range contains 50% of the rankings.

a least preferred method. However, among the seven braille readers, 4 of them also ranked it as a least preferred method. None of the participants ranked braille as highest ranked. These findings are similar to those of Golledge, Klatzky, Loomis, and Marston (2004), who found braille users to be indifferent to braille output for their GPS-based personal guidance system, while nonbraille users found it unacceptable.

SPEECH USER INTERFACE MODE

The participants were asked about how they would prefer to request information about environmental objects through a menu system in which a list of choices of what can be recognized is offered and the user chooses one; a query system, in which the user initiates a request for what she or he wants the device to recognize and/or locate; or a stream of continuous speech, in which all the objects that the system can recognize are read out to the user. Results are shown Figure 2. There was a significant effect of output mode ($\chi^2 = 7.4$, df $= 2$, $p = 0.00$). Only one subject chose menu as a first choice; nine selected one of the other two. A stream of continuous speech also ranked as a third choice (of three) for half the subjects, but two participants chose this as their first choice. The query system was selected as the highest preference by 7 of 10 subjects.

INPUT MEDIUM

For user input, participants were asked to select a preference for either a limited-vocabulary voice recognition system

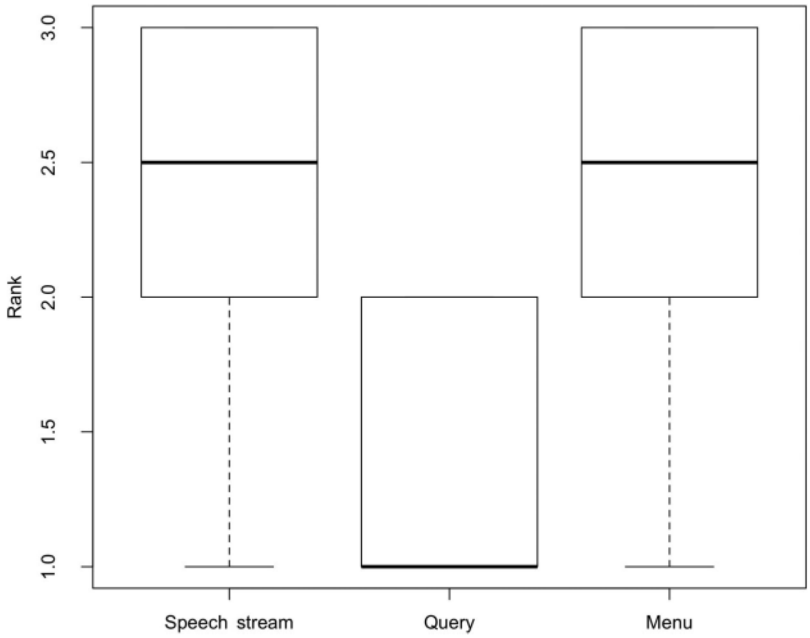

Figure 2. Rankings of preferred interaction with the device.

(where recognition itself would not pose a problem) or a simple keypad that might require more learning and memorization of commands. Eight of the 10 participants preferred the keypad, a significant difference ($W = 80$, $p = 0.01$).

CLASSES OF ENVIRONMENTAL OBJECTS

Participants were asked to rank the usefulness of identifying and locating specific kinds of environmental objects, choosing from "persons"; "furniture"; "architectural features such as doors and stairs"; "text signage"; or "personal objects like keys, phone, wallet, etc." Each of the categories was ranked highest in priority for at least one participant. Significantly, architectural features were ranked 1 or 2 for all 10 participants (see Figure 3). There was thus a strong effect of environmental object class ($\chi^2 = 13.04$, df = 4, $p = 0.01$).

CAMERA LOCATION

Miniature cameras can be mounted unobtrusively in many locations in a wearable system. We asked participants to select which location would work best for them among "on the crest of a baseball cap"; "on the nose bridge of a pair of glasses or sunglasses"; "hand held"; "clipped on clothing like a campaign button"; or "another location." Five of the participants chose "glasses or sunglasses." Two offered tailored responses in the "other" category: "hung around the neck like a pendant" and "worn on the wrist." Three of the participants offered that an additional feature would be beneficial: the ability to aim the camera manually. None of these results, however, was statistically significant. While we suspect that in a larger study, "glasses or sunglasses" might be significantly preferred, we were also surprised at the diversity of

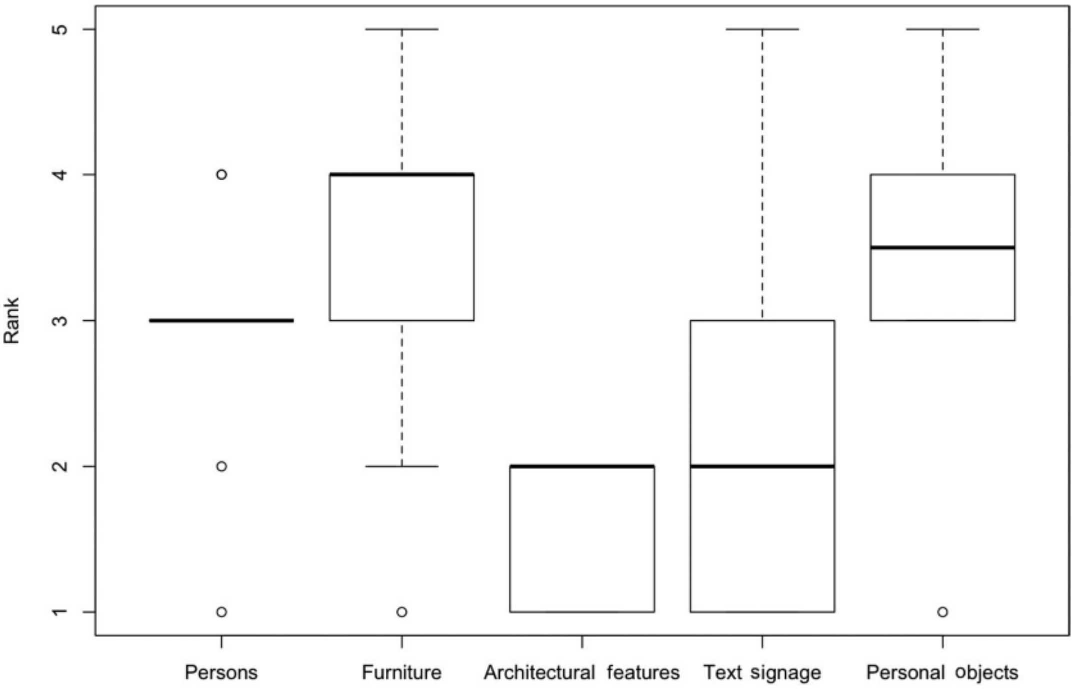

Figure 3. Ranking of usefulness for identifying and locating different classes of environmental objects.

responses to this item, and feel that the issue of where the camera should be mounted and whether it should be capable of being manually aimed is worthy of further study.

ELECTRONIC OR ACCELERATED SPEECH

All 10 participants were accustomed to listening to electronic speech, both through computers and older audio reading devices such as the Victor Reader. We asked them about accelerated speech, since this is a way to increase the information rate of speech output. We asked them to estimate, as a percentage, the speed increase relative to normal speaking that they customarily use. All 10 participants said they used accelerated speech, and most reported using the speech acceleration settings in JAWS, a popular screen reader. The median percent increase reported was 35, with a range of 15–100%.

UNOBTRUSIVENESS

We asked participants how important it is to them—among "very important," "somewhat important," "neutral" and "not important"—that they blend in with the general public so that a device they are using "does not show obviously that you are visually impaired." Seven of the 10 participants ranked unobtrusiveness as "very important" or "somewhat important," while one participant was neutral and two rated it as "not important." This is consistent with the Golledge et al. (2004) study, in which more than half the participants expressed concern with "appearance" of wearing a personal guidance system in public.

GENERAL USE

Participants were asked to prioritize in rank order the most important general uses to them for a portable camera-based device, among the following: "Accessing text signage, such as street signs, indoor signs labeling doors and directional signs"; "Navigating safely around obstacles"; "Identifying and determining the locations of objects (which may include people) in my immediate vicinity"; "Being able to safely and independently find my way to where I want to go within unfamiliar buildings"; "Being able to safely and independently find my way to travel by foot in unfamiliar outside locations"; and "Accessing text on near objects, for instance, book spines, products on store shelves, labels on hand-held products."

Surprisingly to us, responses were evenly spread on this, with little agreement among the participants, although it is interesting to note that the two items involving text (accessing text signage and accessing text on near objects) were ranked highest by 6 of the 10 participants.

Discussion

A clear message for designers of such devices from our participants is that they have a real preference for a mode of interaction with our envisioned device that places control squarely with the user (see, for example, Figure 2). A continuous speech system allows a user control only over what they attend to; a menu system allows the user control, but the device initiates the dialog. It is only a query system that allows users to initiate and issue requests to the device as to what objects to recognize and locate. It is possible that this preference reflects in part the relative expertise and familiarity with assistive technologies of our participants, but it seems equally reasonable to suppose that users might want to have maximum ability to control the output of the device in order to exert control over what they are attending to—device or natural acoustic environment.

Participants overwhelmingly preferred a keypad to a voice recognition system for providing input to the device, even when specifically told that the recognition system would have no difficulties with extraneous noise or poor recognition and that the keypad would require learning and memorization. This result contrasts with the Golledge et al. (2004) finding for a preference of voice input for a global positioning system–based personal guidance system, but we believe this may have to do with differences between such a system (which is used primarily outdoors while traveling) and our envisioned camera-based device (which may be used indoors as well, and often in the vicinity of other people).

We found it interesting that speech was the preferred mode of presentation for receiving information about the environment while navigating (see Figure 1). Most travelers who are blind highly value the acoustic information they receive about the environment and rely on it for many things, including determining direction of vehicular traffic, acoustic landmarks, and echolocation, so the benefit of speech information that might mask other sounds important for traveling safely must exceed the loss or degradation of other acoustic information. The advantage of nonacoustic displays in avoiding acoustic masking is often considered an essential element of an effective electronic travel aid (Dakopoulos & Bourbakis, 2010), but the present results confirm the earlier finding of Golledge et al. (2004) and suggest that blind persons are willing to sacrifice some acoustic environmental information for a device that provides useful navigation information.

Given that the median speech rate customarily chosen by our participants in computer use is accelerated by 35%, we believe that substantial navigation information can be conveyed this way. There is evidence, however, that experienced computer users who are blind are capable of understanding and comprehending much higher rates, averaging about 60% faster than device default text-to-speech rates and up to 2.8 times faster, corresponding to about 500 words per minute (Asakawa, Takagi, Ino, & Ifukube, 2003). We suspect that the speech rate settings in JAWS and perhaps other screen readers do not reflect accurate acceleration percentages. It is also likely that users set accelerated speech rates to slower rates than they are capable of comprehending. In any case, should a device provide speech output, it is feasible to increase the information rate by accelerating speech output to a substantial degree. Indeed, successful virtual verbal displays for navigating and wayfinding have been described by Loomis, Golledge, and Klatzky (1998), and Giuidice, Bakdash, and Legge (2007). The present results support the feasibility of such displays in a camera-based aid.

An informative result in this small study is the ranking of usefulness of identification and location of specific classes of objects (see Figure 3). Architectural features including doors and stairs ranked highest, possibly reflecting the importance of such features for entrance and egress to proximal spaces relative to proximal obstacles like furniture (a problem already well managed with cane or dog guide use), or personal objects (managed by consistent placement nearby or within the home). Location of persons is usually evident from acoustic cues. Text signage, which also ranked high, may have been ranked slightly less so due to participants' relative lack of experience in gaining useful information from visual signs. (Braille and raised text signs are of extremely limited value if one cannot locate them by touch.)

There are several limitations in the present study. First, we assume that our participants have familiarity with all of the interface elements we describe. We believe this is not a serious issue for the present study, since most (but not all) of the technology elements we probed are fairly common, but our participants may not envision these elements in the same way, or in the way we are intending to portray them. Most of the items we asked our participants to rank are only vaguely described, and we provided no concrete examples that might sharpen the precision of their responses. Second, subjective rankings are inherently ordinal at best. That is, the difference between a participant's ranking of "1" and "2" is not necessarily (or even likely) to be the same as the difference between "5" and "6." This problem is partially obviated by our use of non-parametric statistics and distribution-free boxplots, but the reader should be discouraged from over-interpreting any of our findings. Third, we used a small sample. It is possible that we would have obtained additional significant differences had we administered the questionnaire and interview to more participants.

Finally, we note that our results are likely not generalizable to the blind population at large, not only because the education level, employment status, and familiarity with assistive technology in our sample are atypical, but more importantly because our sample consisted only of those with very low or no vision rather than being inclusive of those with significant usable vision. We view this as a strength, however, since this is the very subpopulation who will benefit most from our envisioned device. As such, we hope we have elucidated some useful preferences of blind users with respect to the human-machine interface that can be useful in the development of camera-based navigation and wayfinding devices.

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