Impact of Expertise on Interaction Preferences for Navigation Assistance of Visually Impaired Individuals

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ABSTRACT

Navigation assistive technologies have been designed to support individuals with visual impairments during independent mobility by providing sensory augmentation and contextual awareness of their surroundings. Such information is habitually provided through predefined audio-haptic interaction paradigms. However, individual capabilities, preferences and behavior of people with visual impairments are heterogeneous, and may change due to experience, context and necessity. Therefore, the circumstances and modalities for providing navigation assistance need to be personalized to different users, and through time for each user.

We conduct a study with 13 blind participants to explore how the desirability of messages provided during assisted navigation varies based on users' navigation preferences and expertise. The participants are guided through two different routes, one without prior knowledge and one previously studied and traversed. The guidance is provided through turn-by-turn instructions, enriched with contextual information about the environment. During navigation and follow-up interviews, we uncover that participants have diversified needs for navigation instructions based on their abilities and preferences. Our study motivates the design of future navigation systems capable of verbosity level personalization in order to keep the users engaged in the current situational context while minimizing distractions.

CCS Concepts

•Human-centered computing → **Accessibility technologies; User studies; •Social and professional topics** → **People with disabilities; •Information systems** → *Location based services;* **•Computer systems organization** → *Sensor networks;*

Keywords

Visual Impairments and Blindness, Personalized Navigation Assistance, Turn-by-turn Navigation, User Preferences

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1. INTRODUCTION

For people with visual impairments (PVIs), integrating non-visual cues for the purpose of creating and maintaining an accurate mental representation of the surrounding environment, while possible [44], can be a challenging task. The sense of sight provides accurate and simultaneous access to spatial information at a wider range and long distance [24]. Instead, non-visual exploration [14] is characterized by a lower sensing range and resolution. Thus, navigating in absence of sight can be slow, cognitively demanding [45], and potentially dangerous [26].

A Navigation Assistive Technology (NAT) is an instrument which aims to provide guidance to PVIs during independent mobility. This can be achieved through sensory augmentation and substitution. For example, computer vision-based approaches can be used to detect visual cues in the environment and then signal their presence through an auditory or haptic representation [27, 10]. Other assistive technologies instead supply contextual knowledge about the surrounding environment beforehand [50, 3, 15], or during [32, 41] navigation assistance.

Prior work has investigated which instructions and which types of information are desirable when providing navigation assistance to PVI in outdoor [29] and indoor [37] environments. However, to the best of our knowledge, no prior work examines how expertise and context influence NAT requirements and the perceived usefulness of the information provided to PVI. Our intuition is that the needs of a user who traverses an environment multiple times change as the user builds and refines the mental model of the surroundings. This is supported by prior findings that show that the target population is not homogeneous, and individual PVI exhibit different behaviors and preferences based on the specificities of their visual impairment, prior experience or context [19].

We performed a user study with 13 blind participants to discover how the desirability of guidance instructions, notification messages and contextual information differs among first time visitors to an environment and those who have acquired prior knowledge and experience. For this purpose we used NavCog [41, 32], a NAT that guides the users with turn-by-turn instructions, enriched with contextual information about the environment. In addition to NavCog, the participants could use their preferred traditional navigation aid such as a white cane or a guide dog. In particular, 8 participants chose to navigate using a white cane, while 5 participants were assisted by their guide dog. The participants navigated through two different routes, one for the first time and one that they previously studied using NavCog Preview [15], a virtual guidance software, and already traversed once using NavCog.

During navigation tasks and follow-up interviews, we uncovered that the need for contextual information decreases with prior knowledge and experience. In particular information on traversed areas and landmarks quickly becomes obsolete. However, landmarks considered potential obstacles or indicative of congested areas are a desired information even later on. Turn instructions, when in correspondence of landmarks, also decrease in perceived usefulness with prior route knowledge. Instead, turns corresponding to floor changes continue to be considered a primary navigation cue, an information backed up by participants' explanations during interviews.

There were also differences in preferences between white cane and guide dog assisted participants. The former were interested in limiting cognitive load and avoiding multiple consecutive instruction during first time visits. Instead, the latter share some of the cognitive burden with their dogs, and therefore could disregard instructions about obstacles, veering correction, and slight turns in paths having no alternate routes. In the following, we detail our findings and generalize the results as design considerations for future, user-aware guidance interaction paradigms for NAT.

2. RELATED WORK

2.1 Navigation Assistive Technologies

Many alternatives have been conceived to assist autonomous navigation of PVI, but since the advent of smartphones more advanced solutions have been proposed in order to satisfy the needs of this population. Considering the characteristics of these technologies, a first group of NATs corresponds to those disseminated in the environment, whereas a second group includes those that are carried by the users. A third hybrid group corresponds to those technologies that are both present on the environment (as transmitters) but that also require of a sensing device carried by the user.

Tactile paving [18] is a NAT built-in the environment (e.g., train station platforms, stairs, footpaths,...) that provides distinctive surface patterns detectable by white cane or underfoot, in order to alert PVI about approaching streets' elements and hazardous areas. Acoustic traffic lights [39] are other NATs found within our cities that assist PVI to locate pedestrian crossing as well as to identify walk and wait periods by means of different sound clues. Others well known NATs found within accessible environments are braille tags, as for instance on lift buttons, used to identify surrounding elements by PVI who use Braille and improve their autonomous navigation.

The most common NAT carried by PVI is the white cane [12], an effective tool to predict nearby obstacles along the user path, but less helpful to detect distant objects or find specific locations. An electronic alternative to the standard white cane, based on ultrasound transmitters and sensors [22] has been developed in order to extend its range for obstacle detection. Other handheld alternatives, based on the smartphone camera and computer vision algorithms, have also been studied in order to identify zebra crossings [27] or traffic lights [28], among other interesting elements for improving autonomous navigation of PVI.

Hybrid NATs, with equipment present both on the environment and carried by the user, are able to achieve advanced and promising solutions to enhance wayfinding by PVI in complex and unfamiliar indoor and outdoor environments. Willis and Helal [49] describe a navigation and location system for the blind using an RFID tag grid. Each RFID tag is programmed with spatial coordinates and information describing the surroundings, installed under the flooring, and used to convey precise location and detailed attributes about the area on the user's phone through RFID readers integrated into his/her white cane and shoe.

Legge et al. [25] developed an indoor navigation system for PVI, consisting of digitally-encoded signs distributed through a building, a handheld sign-reader based on an infrared camera, image-processing software, and a talking digital map running on a mobile device. Navcog [41, 32] is a smartphone-based navigation system for blind users. The system makes use of a network of Bluetooth low energy beacons for accurate real-time localization over large spaces, and besides turn-by-turn navigation instructions it also informs the users about nearby points-of-interest (POIs) and accessibility issues.

2.2 Interaction Paradigms for NAT

Most NAT for people with visual impairments use audio and/or haptic feedback as the main modalities for guiding or assisting users during navigation. Feedback is targeted at guiding the user either to a particular destination or to avoid obstacles, and at describing the surrounding environment. A number of NAT for outdoor environments, such as BlindSquare [5], iMove [19], or 'What's around me?' [6] convey auditory information about relevant POIs in the vicinity of the user. These applications usually announce the nearest places around the user, including their distance and orientation, but do not provide turn-by-turn guidance. They also often support a Look Around mode (as in [5]), where the user can point the phone to a particular direction to know the POIs and street intersections located in that particular direction. Most turn-by-turn NATs also rely on auditory feedback, sometimes complemented with tactile commands to reinforce specific instructions (e.g., in the NavCog app [41] the smartphone vibrates when the user is required to turn, and after reaching the correct orientation).

Alternatively, a few solution use haptic feedback [9, 21, 42] or sonification [2, 1] to help guiding the user and keeping them in the correct orientation. Other line of research focuses on conveying information about obstacles in front of the users in order to help them avoiding them. Most approaches also use sonified and/or haptic feedback to convey information about the closest obstacles [8, 11, 23, 51].

Researchers have also been investigating how to better convey visual information and navigation instructions to blind users. For instance, a number of projects have focused on understanding what kind of information is relevant [7, 30, 40, 37, 46, 48]. Other relevant works focus on understanding how instructions should be conveyed to the user, by understanding how blind people verbalize a route [31, 33, 43, 46].

2.3 Effect of Learning on Navigation

Prior research uncovered that mobility regulations [3], environment characteristics [20, 17, 16] and cultural aspects [2] all have a significant impact on the assisted guidance for PVI, and therefore that navigation assistance needs to be context-aware in order to provide suitable instructions [35]. Additionally, user capabilities [4], personal preferences [19] and behavior [17] were also shown to influences the outcome of guided navigation. Thus, NAT need to be capable of adapting to the user needs in order to provide appropriate navigation assistance instructions. However, user characteristics are not immutable, and may change based on new experiences and learning. Indeed, seminal work has studied how user responses to navigation instructions vary based on prior experience with the NAT [2] and repeated experience of the environment [34].

In this work we further advance the state of the art by investigating how the desirability of different types of instructions varies with prior knowledge of the environment. That is, which instructions tend to become obsolete for users that already have the knowledge of the traversed environment. In this work, such knowledge is built through virtual navigation [15], before actually visiting the environment.

3. EXPERIMENT

The experiment focused on understanding if the messages provided by a turn-by-turn NAT were desirable by PVI during guidance, and we analyzed the impact of user's characteristics on the message desirability. Furthermore, we wanted to assess the differences in message desirability between first time navigation in a new route and a navigation after already having acquired prior knowledge and having experienced the route.

3.1 Apparatus

In the real-world experiment, in addition to their usual navigation aid (guide dog or white cane), all participants carried an iPhone running the third version of NavCog audio-based turn-by-turn navigation assistant [41]. This version was modified with respect to the published software[1], with two additional functionalities. One is to record the application usage during experiments, and the other one is to disable the volume buttons which, instead, are used during the experiment by the participants to record those interactions with the app that they did not find useful. Since the experiments focus on the perceived usefulness of the NavCog instructions, we identify the messages types provided by the system (see Table 1) and group them in four categories based on their function:

"Summary" messages - provide information about the route

"Instruction" messages - instruct the user to perform an action

"Notification" messages - update the user on the navigation

"Information" messages - signal the presence of landmarks

For three days prior to the navigation experiment, the participants have used NavCog Preview [15] software to form an initial knowledge of one route. NavCog Preview is an iOs app that allows the exploration of routes through screen gestures and body movements. The messages provided by NavCog Preview are identical to NavCog messages. This initial phase was performed remotely, and the usage logs of the exploration were sent by the app to the research team.

During the navigation experiment, the participants were recorded using two GoPro 4 cameras. One carried by one experimenter while the other one was worn by the participants using a chest strap. This allowed us a better view at the navigation from the participants' point of view. During navigation, the participants used a set of Bluetooth bone conducting headphones to listen to the auditory output from the navigation app. This was done as a safety measure since it allowed the participants to not isolate their sense of hearing to use the app.

3.2 Experimental Setting

The experimental setting was prepared on a university campus across three buildings, spanning eight floors of the first building, one floor of the second building, and six floors of the last building. Additionally, two connecting indoor passages between the first two and the last two buildings were also instrumented. In total, an area of $58,800m^2$ was covered with 884 Bluetooth beacons. For the study we used four routes within our environment, labeled **A**, **B**, **C**, and **D**. All four routes, shown in Figure 1, were between 200 and 220 meters long and spanned across two floors. The routes were similar in complexity, and included 12 turning points and 22 additional information messages.

Each participant explored either route **A** or **B** using NavCog Preview software during three days prior to the real-world navigation. During real-world navigation, the participants would traverse the previewed route and one of the other two routes (route **C** or **D**). Both the routes and their order of navigation were counterbalanced.

[1] https://itunes.apple.com/us/app/navcog/id1042163426

Table 1: 29 **Message types provided by NavCog**

	Message	Example
Summary	Distance	"200 meters ..."
	Destination	"... to the office of the director of the machine learning department"
Instructions	Preview	"Proceed 10m and turn left"
	Turn	"Turn right"
	Slight turn	"Turn slight left"
	Veering correction	"Veer left"
	Consecutive turns	"Turn left" ... after a short distance ... "turn right"
	Turn at landmark	"Turn at plants and chairs"
	Turn at floor change	"Turn at floor change to tiles"
	Turn at corridor end	"Turn at the end of corridor"
	Elevator	"Take the elevator on your left"
	Reached floor	"After reaching the 5th floor, turn left"
Notifications	Warning	Ping and vibration before turn message
	Confirmation	Ping and vibration after correct turn
	Distance	"15 meters ... 10 meters"
	Approaching	"Approaching" when in proximity of turn
Information	Entering area	"Entering Robotics Institute"
	Area	"Library on your left"
	Service	"ATM on your right"
	Landmark	"Plant on your left"
	Column	"Columns on both sides"
	Door on the path	"There is a door"
	Floor change	"Floor change to carpet"
	Obstacle	"Obstacles on both sides"
	Trash can	"Recycle bin on your right"
	Restroom/Fountain	"Water fountain on your left"
	Elevator buttons	"The buttons are between the doors"
	Buttons in elevator	"The buttons are on the right"
	Reached destination	"You have arrived, the restroom is in front of you"

3.3 Participants

We advertised our user study through a local mailing list of people with visual impairments. We recruited 13 participants that were available for both the initial exploration and the real world experiment. Of these, 5 participants were assisted by guide dogs, while 8 participants used the white cane.

The demographic data for the participants is shown in Table 2. The participants had an average age of 55.31 years (STD = 11.72). All participants have used a smartphone for at least one year (AVG = 4.1, STD = 2.3). Participants reported their confidence in their smartphone skills and O&M skills on a 1-7 Likert scale.

Most participants had high self-assessed smartphone (mean = 5.6, STD = 1.0) and O&M (mean = 6.2, STD = 0.8) confidence scores. One possible reason is that people who are more confident and tech savvy are more prompt to participate in experiments such as this one, particularly because they needed to travel to our university campus. Still, it is relevant to note that self-assessed expertise is not necessarily an accurate indicator of actual O&M capabilities. Also, we found no statistically significant difference between the two groups with respect to age, O&M expertise, and smartphone usage and expertise.

Table 2: Participants' demographic information.

ID	Gender	Age	Visual condition/acuity	Onset age	Smartphone	Smartphone confidence	Aid	O&M confidence
1	Male	41	Totally blind	16	6 years	6	dog	7
2	Male	43	Light sensitivity	21	3 years	7	cane	5
3	Female	62	Light sensitivity	0-10	8 years	7	dog	6
4	Female	69	Totally blind	0	2 years	7	cane	6
5	Female	58	Totally blind	17	6 years	7	dog	4
6	Male	42	Shapes, unusable due to glare	0	2 years	5	dog	5
7	Female	44	Totally blind	0	3 years	7	dog	7
8	Male	64	Totally blind	0	8 years	6	cane	7
9	Male	70	Light sensitivity	0	3 years	6	cane	6
10	Male	69	Light sensitivity	40	2.5 years	6	cane	4
11	Female	65	L: blind, R:<20/400, limited FOV	50	5 years	6.5	cane	6
12	Female	47	Totally blind	0	1 years	5	cane	5
13	Male	45	Totally blind	25	4 years	5	cane	5

3.4 Procedure

Our experimental protocol consisted of two stages; an initial learning stage and a follow-up navigation stage. During the learning stage, the participants used NavCog Preview to acquire knowledge about one route prepared in our experimental environment. The participants, after filing the consent form for the study and after reading an initial introduction of the system sent by e-mail, could explore each route for up to 20 minutes during every day of the learning stage. They were instructed to not use any kind of external recordings to study the route independently from NavCog preview.

After each day the participants were contacted by phone and were asked to describe everything they could remember about the studied route to assess their knowledge. We consider the description provided by the participants for the third day as a metric of their knowledge of the route.

We measured the number of instruction and information messages that the participants recalled and correctly positioned in sequence within the described route. There were a total of 12 turn instructions and 22 additional information messages provided during previews, for a total of 34 messages. We were not interested in participants recalling the exact distances or the side of the path on which the information appeared. In Table 3 we report which routes the participants explored, the time they used for the exploration, and the knowledge score assessed after the previews.

The day after the preview, the participants performed the second stage of the study in our experimental environment. We first collected the demographic information about participants and provided an initial introduction of the system capabilities and interaction. A small practice route was used to allow the participants to experience how NavCog system works. Afterwards, the participants performed a series of two navigation tasks in alternating order.

Task a) consisted of two parts. During the first part, the participants were instructed to navigate through the environment following the instructions provided by NavCog, and to press one of the volume buttons each time they were provided an instruction or message that they did not find useful as first time visitors in a new environment. NavCog recorded the volume button presses in its navigation logs, and they were afterwards used for the following data analysis. This way, the participants were motivated to think about the instructions given while navigating, and to actively interact with the system only when they were not interested in a message. We considered this approach less cognitively demanding than having to interact with the system for all desired instructions.

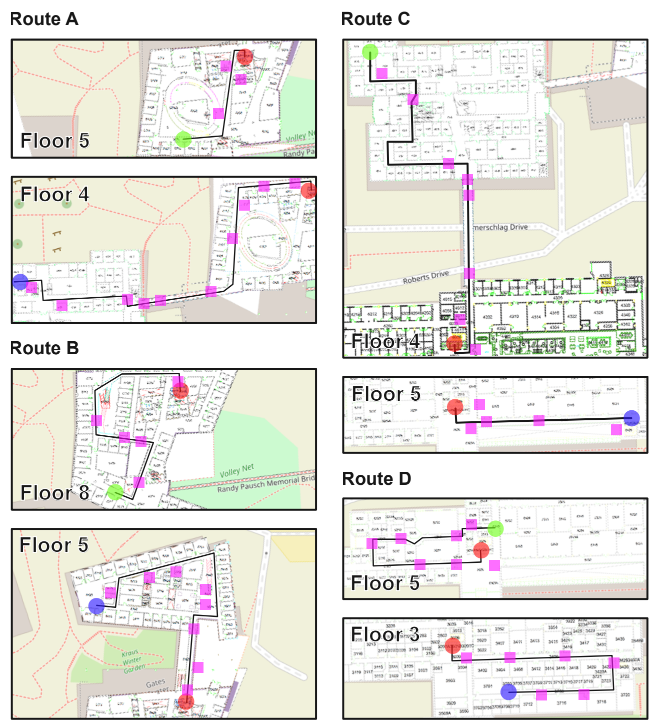

Figure 1: The four routes used during the experiments. Blue dots are the starting points, Red squares are the elevators, and Green squares are the ending points. All squares represent points at which additional information messages were given.

Afterwards, an experimenter engaged the participants in a walking interview, during which they would walk the same route again. Since an experimenter assisted the participants during the walking interview, there was no need to use NavCog or other NAT. During the walk, the experimenter would ask, for each message provided during the previous navigation, if the participant flagged the message as undesired, and why. We also integrated the messages flagged as undesired with corrections from the participants during the interview. For example, sometimes the participants erroneously flagged a message as undesired during the task or, more often, they forget to flag a message because they were concentrated on the navigation.

Table 3: **For each participant: routes used during the study, time spent on the preview, final knowledge score, number of undesired features selected during the study (flagged_features + additional_interview_features - erroneously_flagged_features).**

ID	Route	Time	Knowledge	Undesired	
				known	unknown
1	A&C	3402s	33	6+10-0	3+5-3
2	B&D	2520s	30	0+13-0	1+0-0
3	A&C	3472s	28	1+19-0	0+1-0
4	B&D	1528s	09	0+5-0	0+3-0
5	B&D	1162s	12	1+4-0	0+5-0
6	B&D	3464s	25	2+4-0	1+1-1
7	B&D	3600s	21	2+8-0	2+5-1
8	A&C	3517s	22	0+5-0	3+1-0
9	A&C	2339s	21	0+16-0	3+1-1
10	B&D	2822s	28	4+7-0	0+1-0
11	A&C	1647s	11	2+1-0	1+0-0
12	B&D	2915s	22	2+4-0	0+3-0
13	A&C	3563s	22	1+2-0	1+0-1

Task b) was performed on the route that the participants studied using NavCog Preview at home. First, the participants were instructed to traverse the studied route in the real-world environment using NavCog. This was done in order to reaffirm their knowledge of the route. Afterwards, they were asked to repeat the navigation, but this time they were instructed to flag those messages that they considered undesired by pressing one of the volume buttons on the smartphone, as done in task a), but considering that they have studied this route at home and that they have experienced the route during real-world navigation. A follow-up walking interview was used again, as in task a), to correct flagging errors and integrate the information collected by NavCog with considerations from the participants.

4. RESULTS

In the following we analyze the data collected during the user study. We first report the outcomes of the learning stage and compute the knowledge score for the participants. Then, we study how the participants' characteristics and the knowledge they acquired through the learning stage impacts the desirability of the messages provided by NavCog during the real-world study. Finally, we analyze how the prior knowledge of a route and the assistive technology used impact individual message type desirability.

4.1 Message Desirability and Expertise

Participants have explored the assigned route using NavCog Preview for 3 days before the experiment. The preview exploration was limited to 20*min* per day. They spent a variable amount of time on the exploration, from a minimum of 1162*s* to a maximum of 3600*s*. On average, the total exploration lasted 2765 seconds for each participant ($STD = 861.7s$).

We computed the knowledge score for each participant as the number of elements correctly localized in sequence of the route studied with NavCog Preview. The maximum possible score of correctly positioned elements was 34. The average knowledge scores steadily increased during the 3 days, from 11.7 on day 1, to 19 on day 2 and 21.8 on day 3. Using Pearson correlation coefficient [36], we discover that the time participants spent on studying the navigation route linearly correlates to the knowledge score of the route, assessed through the interviews ($\rho = 0.73, p < 0.005$).

While guided by NavCog, the participants flagged different messages as undesired 36 times. During the walking interview, however, participants updated this score with 124 additional messages, while in 7 cases the participants asked to exclude messages that they previously flagged. Thus, the total number of undesired messages is 153. The number of added and deleted messages per participant is listed in Table 3.

We measure the precision and recall metrics [38] for the message flagging procedure with respect to the results obtained through the walking interview, resulting in a precision score of 0.8 and a recall score of 0.19. The low recall score was expected since the participants were focused on the navigation task and would frequently forgot to press volume buttons during the procedure. P3 clarifies this matter:

> "It's a good thing we did a second walk-through because I should've been hitting those volume buttons a lot and I wasn't"

In total, for the unfamiliar routes, participants signaled 34 messages out of 377 as undesired (9% of the cases). Instead, 32% (119) of messages were signaled for the previously studied route. Using Fisher's Exact Test [13], we verified that the difference between the number of messages flagged as undesired for known and unknown routes is statistically significant ($p < 0.0001$). Participants using a white cane were responsible of 78 (51%) of the 153 messages flagged as undesired, while 49% of the undesired messages (75) were produced by people assisted by guide dogs. The difference in number of messages is statistically significant also in this case ($p < 0.0006$).

Another interesting result of our study is that discarded message types were also shown to vary based on participants' knowledge of the route. We separate the participants knowledge score into high (25 or more), medium ($21, 22$) and low (12 or less). We notice that participants with high knowledge of the route discard messages considered fundamental for others (elevator instructions, door and floor type information). Instead, participants who struggled in acquiring route knowledge during the initial learning stage, choose to discard non vital messages, such as trashcans, on unknown routes. Medium knowledge users are somewhat divided between the two behaviors, without a clear separation based on knowledge score. Therefore, it appears that users that easily memorize routes actually require only less memorable information, while others need least possible distracting messages when learning a route.

The analysis of the Pearson correlation coefficient shows that time spent by the participants studying the route during the learning stage does not directly correlate in a significant way to the number of discarded messages during the navigation tasks. Instead, the knowledge score was found to strongly correlate to the number of discarded messages ($\rho = 0.66$) with statistical significance ($p < 0.015$).

We also noticed that some of the participants who had relatively lower self-reported confidence for either O&M or smartphone usage (P2, P6, and P10) were actually among the ones with the highest knowledge scores and effective capability during navigation, and vice-versa. In general, we think that more confident users will be the ones that appreciate the most the ability to personalize their navigation experience, meaning that our participants (who had high smartphone and O&M confidence levels) probably had a higher amount of discarded messages than what novice or less confident users would have. However we also think that with prolonged usage such differences would attenuate or disappear as users acquire more confidence.

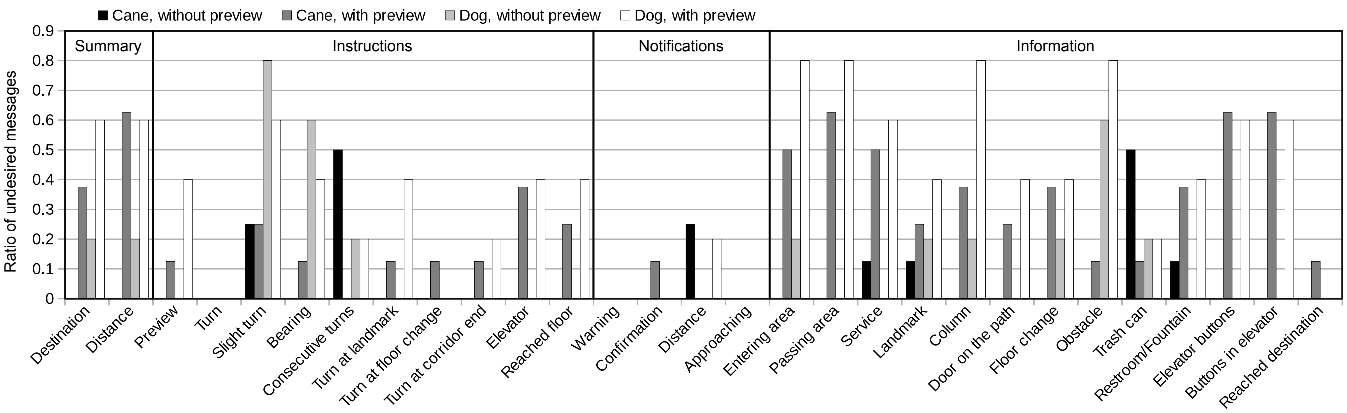

Figure 2: Ratio of undesired messages by message type, aggregated by navigation aid used and by route prior knowledge.

4.2 Message Desirability and Message Type

Figure 2, shows the incidence of undesired messages per message type, categorized by known and unknown routes and navigation aids used by the participants. Messages that inform the user on areas entered (such as buildings or departments), are discarded by 10 out of 13 participants on a known route. Instead, only one participant found this information undesired on new routes. The difference is statistically significant ($p < 0.001$). Similarly, information about nearby areas such as laboratories or departments is considered undesired by 7 out of 13 participants in a known environment, and never in an unknown one. This incidence is also statistically significant ($p < 0.0005$). Service areas, such as kitchens or ATMs, are also similarly affected. This data is discarded 7 out of 13 times for known routes and only once for unknown routes ($p < 0.03$).

Information and Instruction messages about elevators are also frequently discarded on known routes. The instruction to board the elevator is considered undesired on known routes by 5 out of 13 participants, while there is consensus on the usefulness of this message on unknown routes. The difference between the two groups is significant ($p < 0.04$) The information on the positions of the buttons outside and inside elevators are disregarded by 9 and 8 participants respectively. In these cases, the information is considered useful for unknown routes by all participants. Thus, for both types of messages we determine statistical significance between travels on known and unknown routes ($p < 0.0005$ and $p < 0.002$ respectively).

Summary information is also discarded by the participants on studied routes. In particular, we find that the route distance information is not considered important by 8 out of 13 participants on the known route. Instead, only P5 reports the information as undesired for the unknown route, due to the difficulty to assess distances based on numerical information. We identify statistically significant difference among the composition of the two sets ($p < 0.0112$).

4.3 Message Desirability and Navigation Aid

We explore the differences on the incidence of undesired messages based on the navigation aid used (white cane or guide dog). Columns information is discarded by 7 out of 13 participants for the known routes, and by one for the unknown routes ($p = 0.03$). However, going more in depth into the composition of the participants who discarded this message we discover that they are mostly assisted by guide dogs (4 out of 5) as compared to white cane users (3 out of 8). Similarly, 50% of white cane users (4 out of 8) are not interested in information about trashcans while navigating new routes. Instead, for previously learned routes, this information is still considered useful, since it is discarded by only 1 participant.

For the Information messages about obstacles, the difference in the number of discarded messages among participants assisted by guide dogs and those using the white cane is statistically significant ($p < 0.0013$). Specifically, participants with guide dogs frequently marked obstacle messages to be discarded: in 4 cases out of 5 on known routes, and 3 times out of 5 on unknown routes. Conversely, only one white cane user discarded obstacle messages in the case of known routes and never in the case of unfamiliar routes.

Participants with guide dogs are also less interested in Slight Turn ($p < 0.05$) and Veering Correction ($p < 0.02$) Instructions than white cane users. Indeed, guide dogs naturally avoid veering, and can follow a path that has minor slight turns without the need to explicitly instruct them. Thus, slight turns are discarded by 4 out of 5 dog-guided participants for studied routes, and by 3 out of 5 on new routes. Instead, for white cane users, the same instruction is discarded by 2 of the 8 participants for both known and unknown routes. Similarly, veering correction Instructions are undesired for 3 out of 5 participants assisted by guide dogs for unknown routes and 2 out of 5 for known routes. For white cane users, however, the Veering correction Instruction is discarded by only one participant for the known routes.

Finally, on unknown routes, white cane users frequently (5 out of 8) expressed the desire to have quick consecutive instructions conveyed in one go as a sequence rather than having such messages conveyed in rapid succession while performing the actions. Indeed, a number of messages conveyed while already performing other actions was found to be distracting and caused participants to miss turns on multiple occasions. This desire was not reported by any of the white cane users for known routes ($p < 0.05$).

5. DISCUSSION

Our experiments confirm that the need for contextual information while traversing a route depends on prior knowledge, navigation aid used, and context. This reaffirms the need for personalized navigation instructions based on user characteristics, capabilities and personal preferences, as well as environment and situation.

5.1 Route Knowledge and Context

Our analysis confirms that the need to be assisted while traversing a route decreases with prior knowledge and experience of the route. For frequently navigated paths this information is habitually obtained through Orientation and Mobility training [47], but for new and unexplored paths we have seen that rehearsing the route in advance, for example by using NavCog preview, also results in improved route knowledge.

A key question is, which messages are useful only during first time visits and which ones maintain usefulness even after forming the knowledge of the environment? We hypothesize that there are three categories of information, and the message types for each category may differ across users:

> **Guidance information** - this category includes information crucial for the navigation task and therefore quickly memorized by the users.
>
> **Confirmatory information** - this category defines those cues that are important to validate that the traversed route is correct.
>
> **Superfluous information** - this category includes information which is not considered useful or interesting by the user.

The information on high level characteristics and key landmarks of the route belongs to the first category. This information is easily memorized and quickly becomes obsolete for most of users. For example, the summary information about the route, which reports its destination and length is not considered useful by most participants after studying a route. Information about areas traversed during navigation, or features such as elevators are also easy to remember since they logically split the route. Similarly, uncommon landmarks and local places of interest, such as printer rooms, ATMs or coffee places were found to be among preferred navigation cues, and therefore also belong to the first category.

Instead, common landmarks, such as restrooms and water fountains, are less memorable as they frequently appear along most routes. However, these cues still preserve their usefulness as confirmatory information even after rehearsing the route.

5.2 Impact of Navigation Aid

The last category includes those messages that are viewed as unimportant for the specific user but may belong into different categories for other users. In our experiments, the navigation aid used by a participant strongly defined the assignment to this category for specific message types. For example, changes in floor tiles are reported to be key landmarks by white cane users (P2, P9, P10), while for participants assisted by guide dogs (P5, P7), who sometimes had difficulties in distinguishing between similar floor types (e.g., tile and wood), these messages are considered superfluous.

Trashcans are reported as non useful for white cane users during the first route traversal. We believe that such landmarks, being common and movable, do not constitute an informative cue. Instead their high frequency in the environment may increase cognitive load during first visits, which is when a traveler needs to focus most on the navigation task. Regarding this, P2 states:

> "It's a combination of risk assessment, the ability of the person and you also don't want to give them too much information"

However, the same user states that any landmark needs to be provided if it is also an obstacle:

> "If there's anything that can become a problem, that a person can bang into it or get hurt or can be a risk then it's good to put it there"

The difficulty in processing a high number of concurrent notifications while navigating is also noticeable for rapid sequences of turns. In those cases, participants (P4, P8, P10, P12) suggested the possibility to convey the sequence of instructions in one go, rather than one at a time while the user is already busy performing other actions.

For participants assisted by guide dogs, instead, there is a low interest in column and obstacle messages. This fact can be explained due to the fact that guide dogs automatically avoid obstacles and protruding structures such as columns and therefore the participants were not endangered or motivated to memorize or use these cues. The same holds for situations in which users are required to perform slight turns or correct their direction. Unless there are multiple paths available, guide dogs naturally address these situations without the need for an instruction (P1, P3, P7).

However, some participants are still interested in hearing those information as they can better understand and predict their dog's behavior. Indeed, P6 states:

> "I still like to know cause if I feel my dog turning I know why she is turning. Cause a lot of times she might pull me to the left because she's getting into something that she shouldn't"

In particular when the guide dog learns multiple routes in one environment, it may be necessary to discern whether the dog is following the correct route. P1 in particular says:

> "The one thing they warned us about when i was in training was that if you are at school or something like that, you might be going to one classroom for for one semester, and then the next semester you might be across the hall. The dog is gonna be patterned to go to the first classroom from the first semester ... it's kinda hard to break that sometimes"

5.3 Limitations

Our study, motivated by the observation that PVI often re-visit and learn their daily routes over time, took a first step towards uncovering the information preferences of users as their expertise develops. While our approach is the first to explore how prior knowledge influences navigation assistance requirements and preferences for PVI, we can see how a longitudinal study could complement and verify the findings. For instance, it is still not clear how fast a PVI builds a mental model of the environment while being assisted by a NAT, as well as how the navigation needs of PVI change during that time. A better understanding of these issues through a longitudinal study is an important step towards a fully realized, expertise personalization NAT system.

In our study participants were asked to flag undesired NavCog messages by pressing the volume button on the smartphone. Afterwards, we validated and integrated the flagged data with participants. However, participants rarely ever flagged messages during the first part. We think that this was due to the high cognitive demand when navigating. This may mean that the answers were biased by the high cognitive load. We will explore automated logging to extrapolate same interaction data without overwhelming the user.

Understanding interaction preferences may also require exploring and evaluating other ways to convey navigation information. Participants also suggested different interaction approaches (P2, P4, P10), such as different verbosity levels for turning instructions, a clearer way to present turn sequences and so on. For example, P10 says:

> "beeps and vibrations the way you have them set up didn't do much for me ... that's why i suggested ... a tone that if you're off course it gets louder"

The participant then showed us LightDetector[2], an assistive app that conveys the presence of light through continuous audio feedback. We will investigate the feasibility of the suggested interaction modalities, possibly by involving those participants in the process.

[2] http://www.everywaretechnologies.com/apps/lightdetector

6. CONCLUSION

We present the results of a user study with 13 blind participants that explores interaction preferences for turn-by-turn navigation assistance. We answer two key research questions: 1) How prior knowledge and experience of a route impact the needs of PVI during guidance? and 2) How the navigation aid preferences influence the needs of PVI during guidance?

For the first question, we uncover how prior knowledge and expertise reduce the need for assistance. However, this reduction is not homogeneous. High level information, such as total route distance, areas traversed and key transit points such as elevators are memorized quickly. Instead, common features are less characteristic of an environment and thus they appear to be harder to map. Notifications and alerts, as well as turning instructions, are least influenced and appear to be always welcomed as confirmation cues.

To address the second research question, we then explore how white cane users' and participants assisted by guide dogs differ in navigation preferences. White cane users, having to explore the environment directly, seem to prefer avoiding cognitively demanding information, such as sequences of consecutive turns or very common landmarks (e.g., trash cans), that would potentially confuse or endanger them. Guide dog users, instead, are not interested in landmarks and obstacles that do not intersect their immediate path, since the guide dog will naturally avoid those.

Such differences in message desirability motivate future work on interaction personalization for navigation assistive technologies.

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