Increasing the Density of Local Landmarks in Wayfinding Instructions for the Visually Impaired

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Abstract Multiple approaches to support non-visual navigation have been proposed, of which traditional auditory turn-by-turn navigational systems achieved high popularity. Despite being modified according to the needs of visually impaired users, the underlying dataset communicated to the wayfinder is sourced primarily from traditional POI databases which are of limited use to blind navigators. This work proposes the use of environmental features spontaneously detected by blind navigators during their everyday locomotion as 'local landmarks' for enriching auditory navigational instructions. We report results of a survey which served to identify such environmental features. Consequently, we propose a list of potential local landmarks for the blind. Next, in a usability study, we demonstrate that enriching traditional turn-by-turn auditory instructions with local landmarks can improve the subjective satisfaction and confidence in navigation. Results indicate that the improvements seem to be achieved even without increasing the subjective complexity of the instructions. Finally we discuss how using local landmarks to enrich auditory navigational instructions can benefit visually impaired users.

Keywords Local landmarks · Wayfinding · Visually impaired

1 Introduction

The visually impaired population face a range of navigational problems different from those experienced by the sighted. Gathering information from the immediate environment without vision is a much slower process and it is limited to one's closest proximity; for this reason, traveling through an unfamiliar area can be a greatly distressing activity. In the context of wayfinder's confidence, one topic

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receiving a lot of attention in the studies of sighted individuals is the inclusion of local landmarks—distinct features of the environment communicated along the route or at decision points. Although the benefit of including landmarks in a route description is clear, relatively little attention has been given to understanding what constitutes as appropriate landmarks for blind travelers. It thus remains unclear whether local landmarks for the visually impaired might similarly increase subjective confidence during travel through unknown areas. This is despite the proliferation of electronic travel aids which assist in interpreting and communicating information from the surrounding environment while providing the blind navigator with environmental details unavailable through the visual sense. This work focuses on (a) identifying suitable spatial elements for selection as local landmarks for the visually impaired individuals, and (b) measuring the impact of including local landmarks in auditory instructions on the subjective satisfaction and confidence of the blind navigators. We hypothesize that increasing the density of local landmarks communicated to the visually impaired navigators *en route* will result in increasing subjectively reported measures of confidence and satisfaction. In the following sections, we review existing work on navigational aids for the blind and point out the research's over reliance on performance measures. Next, we present results of a questionnaire that identified a number of commonly encountered environmental features used by the visually impaired in their everyday locomotion. Lastly, we construct and evaluate a set of navigational instructions enriched by the presence of the newly identified local landmarks.

2 Related Work

2.1 Wayfinding, Wayfinding Assistance and Landmarks

Navigation is an activity traditionally considered to consist of two components: *locomotion* and *wayfinding* (Montello 2001, 2005). Locomotion is the process of moving one's body across space without the need to consider spatial information other than what is immediately available to us. It involves movement around obstacles, selection of surfaces to stand on, passing through openings or moving towards perceivable landmarks. Wayfinding involves the activity of planning efficient routes in a goal-oriented manner, using the cognitive model of space, often based on information that is not directly accessible at the starting location (ibid.). Navigating through space usually (but not always) consists partially of each of these two components, although the proportions of their importance might vary greatly. Montello (2005) gives the examples of a bus passenger moving their body without much planning (other than at the moment of getting on and off the bus) and of a blind person, who might locomote efficiently through their direct surrounding but may experience troubles orienting themselves with respect to distal landmarks.

The process of wayfinding can be supported by providing users with navigational information at each decision point, which–together with the development of GPS technology and location based services–has become the dominant approach in turn-by-turn navigation assistance systems. This approach, while being widely used, has been shown to bear many disadvantages, such as decreasing the user's ability to build a cognitive representation of their traveled area (Burnett and Lee 2005). Common examples include car navigation systems as well as foot navigation instructions provided by commercial smartphone applications.

Humans naturally use landmarks in their mental representations of space (Montello 1998) and in communicating routes to each other (May, Ross, Bayer, nd Tarkiainen 2003; Michon and Denis 2001). Enriching wayfinding information with landmarks has therefore been shown to benefit navigators (Deakin 1996) and has since been adapted in some commercially available GPS-based systems.

While a method for predicting what constitutes a (good) landmark is a topic open to intensive investigation (Caduff and Timpf 2008; Miller and Carlson 2011; Richter and Winter 2014), the underlying assumption is that correct identification and inclusion of landmarks in wayfinding instructions is beneficial to the wayfinder's performance (Deakin 1996), route memory (Denis, Mores, Gras, Gyselinck, and Daniel 2014) and the construction of one's cognitive map (Schwering, Li, and Anacta 2013). Highlighting landmarks located along the route in wayfinding instructions can also help navigators to build a mental representation of the presently unfamiliar part of the route. This serves to prepare them for challenging stretches of the travel (Michon and Denis 2001). Therefore, while landmarks can be beneficial to the spatial memory and performance of the navigator, a significant part of the benefit lies in the users' subjectively perceived satisfaction and confidence *en route* through an unfamiliar environment. The subset of landmarks located along a specific route, i.e. along straight stretches of road and at decision points, has been termed *local landmarks* (Raubal and Winter 2002).

2.2 Navigational Aids for the Blind

One of the key challenges faced by the blind population is independent travel (Giudice and Legge 2008). As studies have shown, the reason behind this, however, is unlikely due to deficiencies in spatial skills (Loomis et al. 1993) but rather in the informational needs which cannot be easily fulfilled without vision (Passini and Proulx 1988). Multiple technological approaches have been suggested to aid the visually impaired population in independent navigation, but none so far have gained or maintained a dominant popularity among users. Giudice and Legge (2008) provide a historical overview of these diverse approaches and outline the differences between them. As they note, the loss of sight often occurs at an older age, when adapting to a new technology might present a serious barrier to users (Giudice and Legge 2008). Perhaps for this reason, GPS-based navigation devices including auditory support remain the most popular. Since their accuracy is limited, they typically are meant to complement, and not substitute, the use of a white cane. This is also dictated by the fact that the use of the cane is ubiquitous among blind navigators and its utility extends beyond the detection of objects within reach. For instance, it also provides echolocation cues through tapping (Giudice and Legge, 2008).

A number of commercial companies, open source initiatives, and research projects have developed navigational systems supporting visually impaired users in wayfinding. To date, the Wikipedia article devoted to the issue lists 23 such GPS-based systems.[1] They typically run on regular smartphones, and can be controlled with a purpose-built interface, based on audio input and output. An important feature is that they attempt to increase the density of communicated Points-of-Interest (POIs). AriadneGPS,[2] for instance, allows the user to add and manage personal POI favorites which can trigger automatic alerts during wayfinding. Another popular application, BlindSquare,[3] integrates the online social network Foursquare, sourcing a larger number of POIs.

The above approaches, however, depend largely on POIs that are contributed to the database *by* the sighted population for purposes considered relevant *to* the sighted population. Without a careful selection of information, using these datasets might create a cluttered set of instructions that are difficult to interpret for blind users (Giudice and Legge 2008). Such POIs are also unlikely to gain the function of local landmarks in the course of non-visual navigation. Traditionally, the process of enriching wayfinding instructions with local landmarks consists of attaching a textual label to a perceivable object, which is unique enough to be conceptually and semantically distinguished from its neighbors (Raubal and Winter 2002). This implies that the landmark is perceptible in the proximity of other perceptible objects of a similar type (i.e. 'non-landmarks'). To a blind navigator, a typical POI (e.g. 'Ben's Cafe') can still be uniquely identified with a textual label, but without access to visual information (and in a busy urban soundscape) the means of matching that label with any actually perceived environmental object is limited. As a result, a blind user might not have the chance to compare it with other environmental objects of a potentially competing level of salience. A solution to this issue could be the inclusion of a denser set of landmark candidates perceivable by blind navigators within their wayfinding instructions; some of which candidates can be then identified using textual labels associated with standard POIs.

While OpenStreetMap (OSM) supports mapping of two types of features driven by the needs of the blind[4] (tactile paving and distinct types of road crossings), the density of those features in the actual urban environment (even assuming they were all mapped) might always remain disproportionally skewed towards most dangerous urban locations. This potentially limits the utility of enhanced systems for

[1]https://en.wikipedia.org/wiki/GPS_for_the_visually_impaired.

[2]http://www.ariadnegps.eu.

[3]http://blindsquare.com.

[4]http://wiki.openstreetmap.org/wiki/OSM_for_the_blind.

'raising red flags' over the course of non-visual navigation instead of supporting cognitive mapping of the travelled area. For the same reason, communicating the location of such real-world features can possibly increase the subjective confidence of the navigator. This confidence, however, would be specifically related to *locomotion* safety and not to *wayfinding* in a way similar to how local landmarks communicated by humans to humans increase such confidence among sighted individuals.

This is a neglected research area. As Giudice and Legge (2008) note, creators of navigational aids for the blind are limited in their understanding of true user needs and wishes. Literature is dominated by evaluations based on the measures of performance, and subjective satisfaction measures are often left behind (but see e.g. Bradley and Dunlop 2005; Golledge et al. 2004). While such performance metrics can be used to estimate the efficiency of the system (e.g. Kutiyanawala et al. 2010), they might not contribute to the understanding of why many similar aids do not gain popularity among visually impaired navigators.

2.3 Wayfinding Instructions for the Blind

With respect to subjective measures, Bradley and Dunlop (2005) studied how blind (compared to sighted) navigators could judge their workload while navigating to four distinct landmarks with the use of different types of instructions. The authors observed that blind participants experienced lower subjective workload when navigating with instructions which contained a larger proportion of cues *alternative to* textual descriptions of street names and regular Points-of-Interest.

The distribution of workload is not trivial. As Giudice and Legge (2008) note, the balance of effort required to conduct efficient locomotion (even without considering wayfinding) is significantly larger for the visually impaired. It therefore could be favorable to communicate wayfinding instructions by building on the effort already required for successful locomotion. The concept of a local landmark that can be perceived by the visually impaired bears the potential for such a role.

Serrão et al. (2012) considered a wide of range of permanent objects inside a building, and created a system with the ability to recognize landmarks potentially useful to blind navigators. In doing so, however, the authors did not focus on the verification of how easy it might be for the visually impaired to detect these objects.

The CrossingGuard system developed by Guy and Truong (2012) provides detailed auditory information about pedestrian crossings as they are being approached by visually impaired wayfinders. Users of the system expressed reduced stress as well as increased comfort and confidence when presented with details about the layout of the tested intersections. The authors used a crowdsourced approach based on StreetView for coding relevant details of the intersection, although the system did not extend beyond the context of a road crossing.

Swobodzinski and Raubal (2009) proposed an indoor routing system based on Orientation and Mobility training, a process which is typically undertaken by individuals after losing sight (Blasch et al. 1997). As part of their algorithm, the authors specify the distinction between four classes of objects known in Orientation and Mobility training as *obstacles*, *hazards*, *cues* and *landmarks*. Obstacles and hazards are objects which need to be avoided while locomoting. Cues and landmarks, on the contrary, are environmental features which can support navigation. While both must be potentially detectable by a blind navigator, the distinction lies in their unique properties. A cue is an environmental feature which–due to its standard and repeatable property—cannot be uniquely identified, while a landmark has distinct properties that make it a salient element of the environment, potentially beneficial for wayfinding. The authors give the examples of a ceiling fan being a cue (if it's one of multiple such fans in the given environment), and of a small fountain in a hotel lobby serving as a landmark. As the authors note, however, the distinction between what constitutes as a cue or a landmark can be ambiguous, since the concept of a landmark could be perceived as any object that has significance to the blind navigator (given their strategies, skills and preferences). This note is supported by landmark research with sighted navigators, which demonstrates that different objects can gain or lose landmark status depending on the circumstances. For instance, even a perceptually non-salient object can become a landmark due to its salient location in space useful for the task at hand (Miller and Carlson 2011). Knowing that visually impaired navigators need to make wayfinding decisions more often and at shorter intervals (Passini and Proulx 1988), the potential for a landmark to become salient due to its salient location in space is much greater in non-visual navigation.

For this reason, communicating the presence of a larger number of perceivable spatial features in wayfinding instructions for the visually impaired introduces the chance of raising the status of an object spontaneously detected through *locomotion* to the role of a landmark involved in *wayfinding*. This could translate to increasing subjective confidence and satisfaction of the blind navigator—an outcome similar to using local landmarks in instructions for sighted navigators, when traversing unfamiliar environments.

This paper therefore aims to build upon the fact that spatial elements without a distinct, visual meaning, can gain salience due to their utility in the everyday locomotion of visually impaired individuals. This work focuses on (a) identifying suitable local landmarks for the blind, and (b) measuring the impact of their inclusion in auditory wayfinding instructions on the wayfinder's subjective satisfaction and confidence.

3 Identifying Local Landmarks for Visually Impaired Wayfinders

In order to verify the relevance of potential environmental features used to enrich wayfinding instructions for the blind, visually impaired navigators were interviewed and asked about their wayfinding strategies. Particular care was given to communicating their abilities to spontaneously detect distinct elements of the environment during everyday locomotion.

3.1 Interview

Ten blind participants (7 men and 3 women) aged between 35 and 68 were recruited with the help of a local association. Seven of them were congenitally blind, two lost sight during mature adulthood and one during childhood. The majority of the participants spoke English; for the two who did not, German translations of all subsequent materials were provided. Standard ethical procedures were applied throughout the study, with participants giving their informed consent prior to the study.

In a semi-structured interview, participants were requested to give an account of their wayfinding strategies. All ten participants reported that they typically used a cane to support their navigation, eight used dedicated smartphone applications, and one participant relied on help from a guide dog. When asked about their use of auditory navigational software, eight participants declared that they used commercially available solutions on an everyday basis. Participants also expressed the preference to loudspeakers over headphones in order to preserve the ability to hear other environmental noise while navigating.

Participants expressed their strong dependence on Audible Traffic Signal (ATS) when crossing the road. In order to estimate the metric range of ATS as a potential landmark, participants were asked to estimate their hearing range of ATS under typical traffic conditions. The estimated distance fell in the range of 5–20 m, with a reported mean of 12.5 m.

A list of potentially relevant local landmarks (i.e. objects or environmental features which can be spontaneously detected and are ubiquitous in the urban environment) has been composed based on previous informal conversations and the existing literature (see e.g. short summary by Bradley and Dunlop (2005) and a list by Strothotte et al. 1995). Participants reported an ability to sense a wide range of materials and objects with their white cane. When asked to select exact objects they considered possible to detect while traveling, their answers were relatively homogenous (see Table 1).

Table 1 Number of participants (out of 10) who answered 'yes' to the question: "Can you detect the following object when traveling on a road?"

Landmark	No. of participants
Access and exit areas	10/10
Traffic lights (ATS)	10/10
Surface materials	10/10
Tactile areas and tactile strips	10/10
Railings	8/10
Walls	8/10
Bus stops with a shelter	8/10
Tree pits	8/10
Staircases	8/10
Bus stops without a shelter	0/10
Others (please specify)	2 mentions of *street gutters*

3.2 *Local Landmarks for Visually Impaired Wayfinders*

Below we provide a list of local landmarks established from the interview. The potential usability of some listed landmarks is supported by literature. In some cases, however, despite being described as easily detectable, their usefulness for navigation is limited due to associated spatial characteristics. For example, following street gutters would often force the user to move dangerously close to motorized traffic.

- **Access/Exit Areas** are sections of sidewalks allowing motorized traffic to access properties across the sidewalk. Typically constructed from a distinct surface material and having a distinct slant (Fig. 1a), there are instances when their utility for non-visual navigation is limited, e.g. when the surface material is uniform (Fig. 2b) or the arrangement is temporary (Fig. 3c).
- **Tactile Areas** (Fig. 2a) are larger planes constructed of tangibly distinct surfaces and of contrasting colors in order to aid navigation of the blind and partially sighted individuals. Typically constructed near junctions, waiting areas (e.g. bus stops), and public entrances, they are purpose-built, and thus of clear utility to visually impaired wayfinders.
- **Tactile Strips** often extend from Tactile Areas in order to aid faster movement along safe pathways (Fig. 2b). Tactile paving is a feature supported by the OpenStreetMap database, though mappers seldom specify its existence. Some commercial navigational applications make use of this database.
- **Tree Pits** are the constructions built around trees for their protection in an urban environment. Often aligned on pathways at regular intervals, they present potentially helpful local landmarks, given that their location lies within the range of a white cane from the safe pathway (Fig. 3a, b). Often, however, tree pits might be located on the outer edge of the pedestrian traffic area (Fig. 3c), in a non-linear manner potentially confusing to the navigator (Fig. 3d), or behind a cycling path (Fig. 3e).

Fig. 1 **a** Slanted, **b** uniform, and **c** temporary access and exit areas

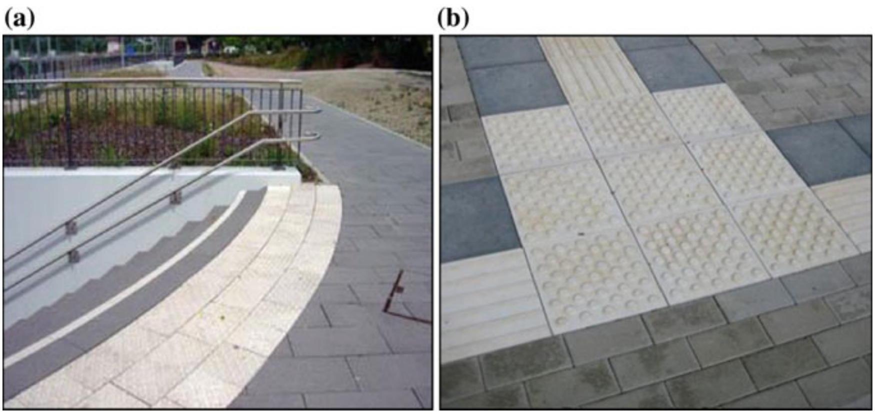

Fig. 2 **a** Tactile area/paving and **b** tactile area connected with tactile strips

- **Staircases** can be easily detected with the use of a white cane. The additional landmark-related advantage of staircases is that they can be direction-specific when the downstairs/upstairs distinction is made. In order to avoid confusion, this work will not use the term 'staircase' when stairs lead directly to a building entrance.
- **Railings and fencing** can be useful non-visual local landmarks when adjacent to the pedestrian area (Fig. 4a) if they are not temporary (Fig. 4b). Due to potential difficulties with the detection of short stretches of railings along long straight stretches of a route, railings are particularly useful when they lead to, or originate from, a turn.
- **Walls,** similar to railings and fencing, can help blind navigators to establish a straight traveling direction (Swobodzinski and Raubal 2009) Moreover, walls help individuals identify turns when arriving at, or departing from a turning point.
- **Audible Traffic Signals** (ATS) are standardized, and in many countries ubiquitous, devices that use sound to indicate the presence of a pedestrian crossing

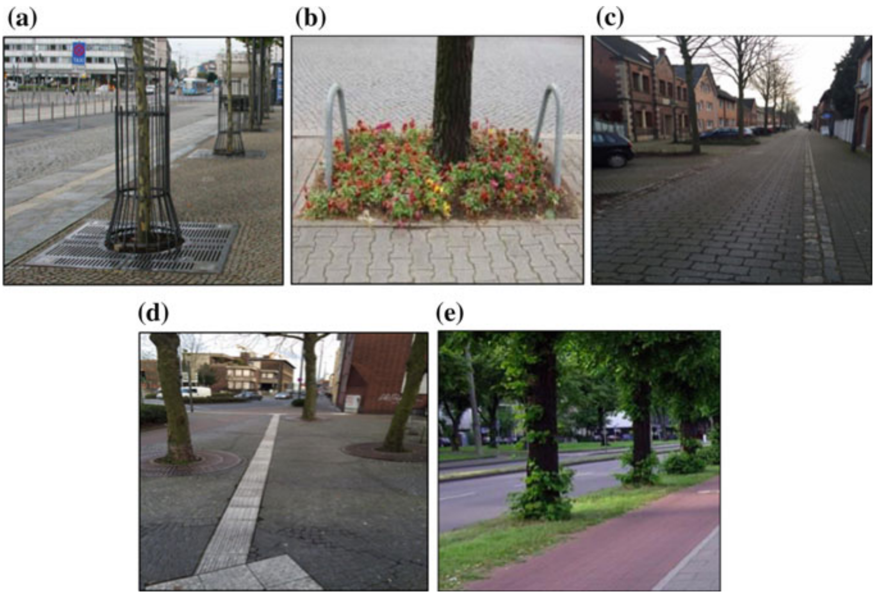

Fig. 3 Tree pits, potentially useful as local landmarks (**a** and **b**) and those of limited utility (**c**, **d** and **e**)

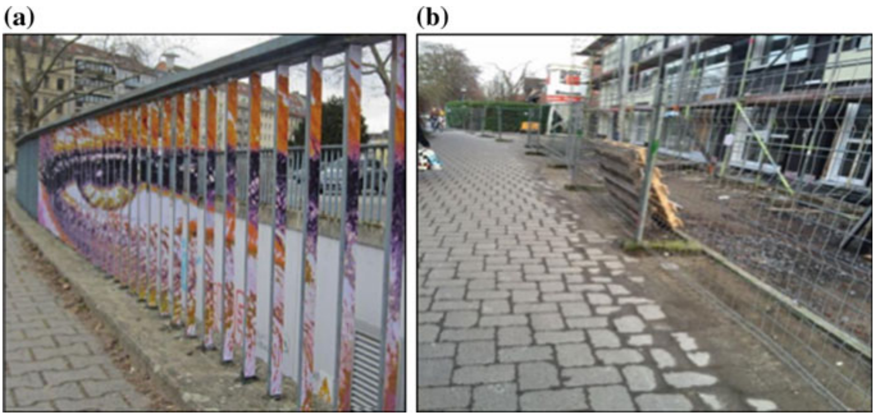

Fig. 4 **a** Permanent and **b** temporary fencing

and vibrations to indicate whether the crossing has islands. As presented in the previous sections, participants differ with regard to their self-reported abilities to locate the ATS signal, with the mean range of hearing reported as 12.5 m. Similarly to Tactile Paving, pedestrian crossings are a feature supported by OSM, with a distinction into multiple sub-categories.

- **Surface Materials and transitions between them** are another environmental feature participants feel confident at detecting. Since these transitions often coexist with other local landmarks (such as Access and Exit Areas), they were not considered separately in the current study.
- **Bus/Tram Stops** were reported to be only easy to detect if a shelter around the stop was present. Therefore, stops without the shelter were not considered as local landmarks.

With regard to the results of the interview, it is worth noting that humans are generally more likely to remember pre-listed objects (Craik and McDowd 1987). Therefore, the frequency of objects not explicitly asked for in the interview is likely to remain underestimated. For instance, two participants mentioned street gutters when asked for 'other possibly detectable objects'. We thus do not claim this list to be exhaustive. Further research is also needed into the factual accuracy with which blind navigators can detect potentially salient spatial elements with regard to 'false positive' and 'false negative' types of error. This can vary especially under the presence of heterogeneous wayfinding strategies and spatial abilities within the visually impaired population (Schinazi et al. 2015).

4 Evaluating Landmark-Enriched Navigational Instructions

4.1 Procedure

A user study was conducted in the city of Münster, Germany with the same pool of participants who took part in the aforementioned interview. The study took place in an urban area selected due to its non-trivial spatial arrangement as well as its accessibility to a location that was known to the participants. Participants were asked to walk the route with the support of audio instructions (played or read by the accompanying researcher at the corresponding location in a 'wizard-of-oz' arrangement; see Fig. 5).[5]

All participants walked the same route, in the same direction which took approximately 12 min. Participants were randomly divided into two groups. Each group traveled half of the route with Landmark-Enhanced Instructions (*LE*) and the other half with regular instructions, without additional landmarks mentioned (*non-LE*). Depending on the group, the order at which the given set of instructions was played varied: the first group was assisted by *LE* for the first half of the route, and *non-LE* for the second. The second group was guided by the *non-LE* instructions for the first half and *LE* for the second half of the journey.

[5]It bears noting that the technique of communicating auditory information is, in itself, a research problem central to separate studies; however, the current work focuses on the content, and not the means of transmitting the landmark-enhanced wayfinding instructions.

Fig. 5 The 'Wizzard-of-Oz' experimental procedure

Each participant was asked twice to respond to a usability questionnaire. This survey was provided to participants half-way through the route as well as at its end. It was made clear that all questions asked were directly related to the recently completed stretch of the route. In this repeated-measure study design, each participant contributed two sets of responses: one for the *LE* and one for the *non-LE* set of verbal wayfinding instructions. The potential effect of order and the resulting linkage between the given route stretch and the instruction type was counterbalanced.

4.2 Materials

The instructions were played to participants over loudspeakers from a text-to-speech software (or read aloud by a researcher[6]) as the participants approached the relevant location. The location of local landmarks was encoded earlier from 3D video data in an effort to verify whether objects identified in Sect. 3.2 could be detected and digitized remotely. A sample set of instructions is provided in Table 2. Note that some landmarks identified in Sect. 3.2 are not used, as the study area did not contain all types of landmarks that would be usable in this wayfinding scenario. For instance, existing tree pits cannot be located too far away from the main line of locomotion.

The *LE* set consisted of 20 commands in total (10 of which mentioned a local landmark), and the *non-LE* set contained 13 commands (4 of which contained a standard POI-like label).

[6]Two participants asked for the instructions to be read in German, instead of the English recordings.

Table 2 Sample comparison of Landmark-Enhanced (LE) and non-Landmark-Enhanced (non-LE) instructions. The non-LE instructions were generated based on existing wayfinding applications for the blind (BlindSquare and AriadneGPS)

Landmark-enhanced	Non-landmark-enhanced
Walk 10 m	Walk 10 m
Turn right and go downstairs	Turn right
Turn right onto access and Exit area for Platten-Peter Fliesenzentrum	Turn right for Platten-Peter Fliesenzentrum
Walk 50 m and pass by access and Exit area	Walk 200 m
Walk 150 m	
Walk 25 m	Walk 200 m
Follow right side small wall	

A custom-built questionnaire was constructed based on the System Usability Scale (Brooke 1996), with additional questions relating to specific landmark properties. Table 3 presents all questions used. Questions were presented together with their German translations. A five-step ‘strongly agree - strongly disagree’ scale was used for collecting responses.

4.3 Results

The main motivation for evaluating local landmarks in this study was to increase subjective satisfaction of the blind participants. For this reason, further analysis does not concern performance measures but focuses on the subjective estimates of the instruction’s usability.

Linear Mixed-Effect Models (Baayen et al. 2008) were used to statistically verify the influence of *condition* (*LE* vs *non-LE*) on questionnaire responses using R and the lme4 package (Bates et al. 2014). Questionnaire items were recoded so that the higher number would always correspond to a more favorable answer. These responses were entered as the dependent variable of the model. Intercepts for *Participant ID* and *Question ID* were entered as random effects, together with the random slope for the *by-participants* and *by-question* effect of *condition*. The *p-value* for the fixed effect of *condition* was estimated using lmerTest package (Kuznetsova et al. 2014) and was equal to $p = 0.0026$. *Marginal* R^2 estimated by the MuMIN package (Bartoń 2014) was 0.18 and *Conditional* R^2 was 0.47.

Landmark-Enhanced instructions significantly increased subjective questionnaire responses of the participants, although the magnitude of improved satisfaction varied across participants, and for individual questionnaire items. After accounting for this by-participant and by-question variability, approximately 18 % of the variance in the responses can be associated with the influence of the instruction type, i.e. *condition* (*LE* vs *non-LE)*.

Table 3 Questions used in the evaluation study

	Question
Q1	I would like to use this system frequently for navigation
Q2	I thought the system has made the navigation more complex
Q3	I found this system has more detailed instruction
Q4	I think I need practice to use this system
Q5	It feels easy to handle this system
Q6	I found this system helps me to identify turns and curves easily
Q7	I found it was harder to find streets and routes with this system
Q8	I thought this system has irrelevant landmarks for guidance
Q9	I found this system leads me to correct path
Q10	I thought the system aids me in identifying the landmarks
Q11	I found the system helps me to travel faster
Q12	I found the system guides me to identify the crossings
Q13	I think I need technical support before using this system
Q14	I could reach the destination precisely
Q15	I felt the verbal command was inconsistent
Q16	I felt very confident using this navigation system

Figure 6 illustrates the mean responses to all questionnaire items together with 95 % Confidence Intervals.

As the sample size was relatively small and the questionnaire was custom-built, in what follows we do not apply dimension-reduction techniques on the questionnaire items but offer an exploratory discussion of individual question-by-question differences based on Fig. 6.

Participants were more satisfied (Q1) with the *Landmark-Enhanced* set of instructions. This was accompanied by higher subjectively perceived confidence (Q16) during navigation, as well as higher perceived efficiency of the journey; navigators felt they were able to travel faster (Q11), and with a higher degree of precision (Q14). The system appeared to have made it easier to identify turns (Q6), pathways (Q7, Q9), and road crossings (Q12). The *Landmark-Enhanced* set of instructions was particularly useful in providing relevant (and subjectively perceived as useful) landmark-related information (Q3, Q10). It seems that the *Landmark-Enhanced* set of instructions provided relevant information (Q8) in comparison to the traditional instruction set. It also seems that the benefits of the new system were not associated with its increased perceived complexity (Q2, Q4, Q5, Q13, Q15).

In short, the *Landmark-Enhanced* set of instructions had a significant influence on the participants' subjective satisfaction and confidence, while it was not seen as subjectively more complex.

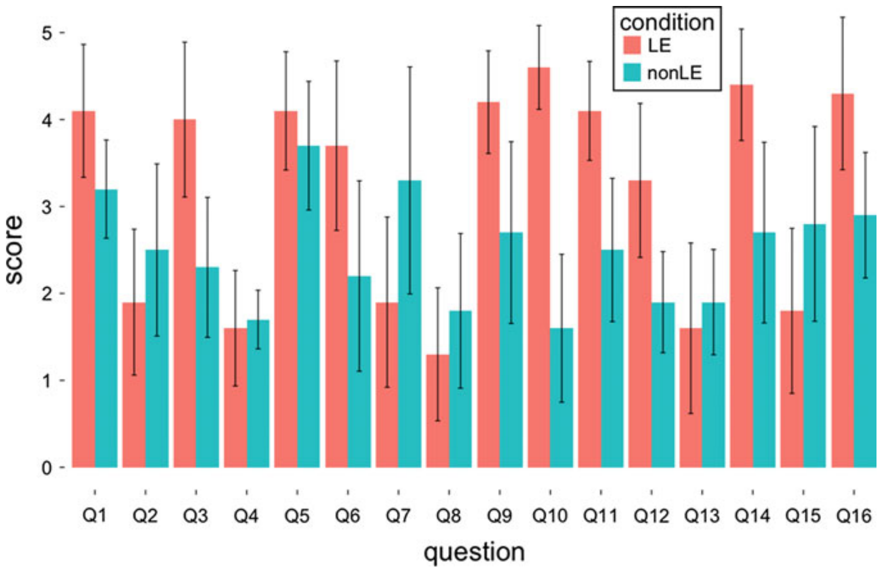

Fig. 6 Mean responses to questionnaire items with 95 % CIs (note that here the values are not recoded: refer to Table 3 for the meaning of a higher/lower response within each question)

4.4 Discussion

Results suggest that traditional turn-by-turn navigational systems for the blind can be improved by the simple means of increasing the density of relevant local landmark information they communicate. For an urban area selected for this study, the density of the newly introduced landmarks did not result in increased subjective complexity. This could become an issue if the communicated information was irrelevant or trivial—imposing an increased load with little benefit to the navigator.

While it is not surprising that the system communicated landmark-related information better than the traditional set of instructions, it is worth noting that subjective satisfaction and confidence were increased by these means. This effect is similar to the effect that local landmarks have on visual navigation, where one of their main advantages lies in increasing the confidence of the navigator by ensuring they stays on the correct trajectory.

An alternative explanation must consider the fact that participants could simply feel more confident when provided with more information making their locomotion easier. This is possible, however the list of communicated landmarks did not contain elements generally considered to be ‘hazards’ or ‘obstacles’ in non-visual navigation. Access and exit areas, walls, tactile paving and staircases are all easily detectable by wayfinders after Orientation and Mobility training, and even form part of their everyday mobility strategies. Nevertheless, having these features mentioned in the navigational process increased subjective satisfaction and confidence.

One related question remaining outside the scope of this study is to what degree can an increase in the density of local landmarks result in the ability of blind navigators to better remember the route or to build a survey knowledge representation of the area? The increased diversity and density of emphasized landmarks can have a role in explicitly differentiating two otherwise similar path sections. This phenomenon has been shown to have a positive effect on human spatial memory in visual navigation (Buchner and Jansen-Osmann 2008).

The selection of relevant local landmarks is another issue deserving further attention. Traditionally, the attractiveness of local landmarks has been defined by visual, semantic and structural attractiveness (Raubal and Winter 2002). In the case of the visually impaired population, the visual aspect clearly loses importance, potentially becoming overwritten by the auditory or haptic properties of the environmental object, as well as the blind navigator's ability to spontaneously identify it through the course of everyday locomotion. It is, therefore, important that the identification of local landmarks does not require additional effort (be it physical or mental)—just as the identification of visual attractiveness of a local landmark does not require 'other than regular' effort in a visual exploration of the urban surroundings by a sighted individual. This property of landmarks might be largely responsible for the low subjective complexity of the tested LE instructions—a relation which is not self-evident. Presenting an increased volume of information in a serial manner (imposed by the auditory medium) is generally associated with increased cognitive load. It therefore appears that the key to useful local landmark selection is in understanding which spatial objects would be detected by the blind navigator spontaneously over the course of regular locomotion. This once again puts the emphasis back on the heterogeneous abilities and preferences of the visually impaired user (Schinazi et al. 2015).

The structural salience of selected landmarks is of no lesser importance. Given a dense set of subsequent local landmarks, all detectable over the course of everyday locomotion by an individual blind user, it might be more beneficial for one's spatial memory to hear the information about some landmarks over others. Environmental elements linked to larger structures (e.g. access areas to large public buildings) can be of particular importance, as they afford the understanding of one's location and bodily orientation at multiple points, with respect to a single feature (e.g. two sides of the same building). At the same time, this creates the potential for confusion, if these spatial relations are not communicated in sufficient detail; knowing that one passes three separate access areas to the same public building over the course of a complex travel might be not beneficial if the relation between these points is not explained. This is an aspect not tackled in this work.

Another view on the structural salience of non-visual local landmarks can consider travel as a movement along a 1-dimensional sequence of auditory landmarks. Then, the concept of their structural salience can be viewed as the landmark's location with respect to other landmarks along that route. The distance between subsequently communicated landmarks, as well as the contrast between the salience of sequentially encountered objects, might provide dominant cues for structural attractiveness.

It is important to note that the current work considers landmarks in relation to environmental elements that do not necessarily have any uniquely identifying properties. Just as 'any' doorway is not a landmark to a sighted individual, 'any' bus shelter, or 'any' access area might not become a landmark to a visually impaired navigator. However, at least two known cases suggest that this potential repeatability and 'non-landmarkness' can be understood differently in the context of non-visual navigation. Firstly, even non-unique structures can have an important status in wayfinding, so long as their location and function make them an important point for understanding one's orientation in relation to the surrounding structures - staircases in complex buildings being one example (Hölscher et al. 2006). Secondly, as locomotion is a more–physically and mentally–demanding activity for the blind than it is for the sighted (Giudice and Legge 2008), the energy spent on an individual's movement along and through these repeatable everyday environmental elements is likely to be greater. The level of one's energy spent on the process of locomotion is linked to spatial learning processes driven by attentional states and heuristic judgment of traveled distances (Montello 2005). A person locomoting with greater effort is, therefore, likely to pay greater attention to one's environment which might translate to a greater ability to distinguish seemingly similar objects and spatial relations between them. In such an approach to non-visual local landmarks, the complexity of the urban environment must also be considered (Gaunet 2004).

The effort has already been made towards creating computational models with hierarchical data structures adequate for the techniques blind navigators use to learn their spatial environment (Gaunet and Briffault 2005; Yaagoubi et al. 2012). A denser set of local landmarks, such as what has been proposed in the present work, can increase the subjective satisfaction and confidence of the visually impaired travelers using systems based on such databases.

5 Limitations and Conclusion

In the current work, the location of local landmarks used in the instructions was digitalized remotely using a 3D video dataset provided by the Hansa Luftbild company. It remains to be evaluated whether all local landmarks identified in Sect. 3.2 can be distinguished for digitization, especially under more heterogeneous urban conditions. Potential alternative sources of delivering this information are worth noting. For instance, Guy and Truong (2012) demonstrated how StreetView could be used for a similar task in a crowdsourced approach. Infrastructural elements which can serve as local landmarks to the visually impaired population are rarely distinguished in authoritative databases at a sufficient level of detail while automated or crowdsourced approaches offer a promising alternative.

It is also worth noting that subjective measures of satisfaction and complexity–while offering a worthwhile perspective on the problem–are not always completely reliable. People have been shown to both under and overestimate their subjective perception of various metrics in usability studies. Further work is required to compare these subjective estimates to alternative measures of cognitive effort. The proliferation of psychophysiological techniques nowadays offers such a possibility in the context of naturalistic navigation (Mavroset al. 2013; Tröndleet al. 2014).

To conclude, subjective measures of user satisfaction and perceived complexity rarely form a part of the evaluation of navigational systems for the blind. The current work proposes that increasing the density of local landmarks in navigational instructions can yield a positive increase over many measures of a user's subjective satisfaction. Future work needs to further investigate the suitability of proposed environmental features for their local landmark status, as well as seek to explore the cognitive benefit that enriched instructions can have on the visually impaired wayfinders.

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References

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412.

Bartoń, K. (2014). MuMIn: Multi-model inference. R package version 1.15.1. Retrieved from http://cran.r-project.org/package=MuMIn.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1–7. Retrieved from http://cran.r-project.org/package=lme4.

Blasch, B. B., Wiener, W. R., & Welsh, R. L. (1997). *Foundations of orientation and mobility*. Amer Foundation for the Blind.

Bradley, N. A., & Dunlop, M. D. (2005). An Experimental Investigation into Wayfinding Directions for Visually Impaired People. *Personal and Ubiquitous Computing*, *9*(6), 395–403. http://doi.org/10.1007/s00779-005-0350-y.

Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability Evaluation in Industry*, *189* (194), 4–7.

Buchner, A., & Jansen-Osmann, P. (2008). Is Route Learning More Than Serial Learning? *Spatial Cognition & Computation*, *8*(4), 289–305.

Burnett, G. E., & Lee, K. (2005). The effect of vehicle navigation systems on the formation of cognitive maps. In *International Conference of Traffic and Transport Psychology*.

Caduff, D., & Timpf, S. (2008). On the assessment of landmark salience for human navigation. *Cognitive Processing*, *9*(4), 249–67. http://doi.org/10.1007/s10339-007-0199-2.

Craik, F. I., & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*(3), 474.

Deakin, A. K. (1996). Landmarks as navigational aids on street maps. *Cartography and Geographic Information Systems*, *23*(1), 21–36.

Denis, M., Mores, C., Gras, D., Gyselinck, V., & Daniel, M.-P. (2014). Is Memory for Routes Enhanced by an Environment's Richness in Visual Landmarks? *Spatial Cognition & Computation*, *5868*(May 2016), 1–39. http://doi.org/10.1080/13875868.2014.945586.

Gaunet, F. (2004). Verbal guidance rules for a localized wayfinding aid intended for blind-pedestrians in urban areas. *Universal Access in the Information Society*, *4*(4), 328–343. http://doi.org/10.1007/s10209-004-0109-7.

Gaunet, F., & Briffault, X. (2005). Exploring the Functional Specifications of a Localized Wayfinding Verbal Aid for Blind Pedestrians: Simple and Structured Urban Areas. *Human–Computer Interaction*, *20*, 267–314. Retrieved from http://gsc.up.univ-mrs.fr/gsite/Local/lpc/dir/gaunet/articles/Exploring the functional specifications of a localized wayfinding verbal aid.pdf.

Giudice, N. A., & Legge, G. E. (2008). Blind Navigation and the Role of Technology. *The Engineering Handbook of Smart Technology for Aging, Disability, and Independence*, 479–500.

Golledge, R. G., Marston, J. R., Loomis, J. M., & Klatzky, R. L. (2004). Stated preferences for components of a personal guidance system for nonvisual navigation. *Journal of Visual Impairment & Blindness*, *98*(3), 135–147.

Guy, R., & Truong, K. (2012). CrossingGuard: exploring information content in navigation aids for visually impaired pedestrians. *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems - CHI '12*, 405–414. http://doi.org/10.1145/2207676.2207733.

Hölscher, C., Meilinger, T., Vrachliotis, G., Brösamle, M., & Knauff, M. (2006). Up the down staircase: Wayfinding strategies in multi-level buildings. *Journal of Environmental Psychology*, *26*(4), 284–299.

Kutiyanawala, A., Kulyukin, V., & Bryce, D. (2010). On Self-sufficiency of verbal route directions for blind navigation with prior exposure. In *Proceedings of the 25th Annual International Technology and Persons with Disabilities Conference (CSUN 2010), San Diego, CA*.

Kuznetsova, A., Bruun Brockhoff, P., & Haubo Bojesen Christensen, R. (2014). lmerTest: Tests for random and fixed effects for linear mixed effect models. R package version 2.0-11.

Loomis, J. M., Klatzky, R. L., Golledge, R. G., Cicinelli, J. G., Pellegrino, J. W., & Fry, P. A. (1993). Nonvisual navigation by blind and sighted: assessment of path integration ability. *Journal of Experimental Psychology. General*, *122*(1), 73–91. http://doi.org/10.1037/0096-3445.122.1.73.

Mavros, P., Austwick, M. Z., & Hudson Smith, A. (2013). Geo-EEG: Towards the use of EEG in the study of urban behaviour, (April), 1–6. http://doi.org/10.1007/s12061-015-9181-z.

May, A. J., Ross, T., Bayer, S. H., & Tarkiainen, M. J. (2003). Pedestrian navigation aids: Information requirements and design implications. *Personal and Ubiquitous Computing*, *7*(6), 331–338. http://doi.org/10.1007/s00779-003-0248-5.

Michon, P.-E., & Denis, M. (2001). When and why are visual landmarks used in giving directions? *Spatial Information Theory*, *2205*, 292–305. http://doi.org/10.1007/3-540-45424-1_20.

Miller, J., & Carlson, L. (2011). Selecting landmarks in novel environments. *Psychonomic Bulletin & Review*, *18*(1), 184–191. http://doi.org/10.3758/s13423-010-0038-9.

Montello, D. R. (1998). A new framework for understanding the acquisition of spatial knowledge in large-scale environments. In M. J. Egenhofer (Ed.), *Spatial and temporal reasoning in geographic information systems* (pp. 143–154). New York: Oxford University Press.

Montello, D. R. (2001). Spatial Cognition. In *International Encyclopedia of Social and Behavioral Sciences* (pp. 14771–14775).

Montello, D. R. (2005). Navigation. In P. Shah & A. Miyake (Eds.), *The Cambridge Handbook of Visuospatial Thinking* (pp. 257–294). Cambridge: Cambridge University Press.

Passini, R., & Proulx, G. (1988). Wayfinding without Vision: An Experiment with Congenitally Totally Blind People. *Environment and Behavior*, *20*(2), 227–252. http://doi.org/10.1177/0013916588202006.

Raubal, M., & Winter, S. (2002). Enriching Wayfinding Instructions with Local Landmarks. *Proceedings of the Second International Conference on Geographic Information Science*, *2478* (1), 243–259. http://doi.org/10.1007/3-540-45799-2_17.

Richter, K.-F., & Winter, S. (2014). *Landmarks - GIScience for Intelligent Services*. Springer.

Schinazi, V. R., Thrash, T., & Chebat, D.-R. (2015). Spatial navigation by congenitally blind individuals. *Wiley Interdisciplinary Reviews: Cognitive Science*, *7*(February), n/a–n/a. http://doi.org/10.1002/wcs.1375.

Schwering, A., Li, R., & Anacta, V. J. A. (2013). Orientation information in different forms of route instructions. In *Short Paper Proceedings of the 16th AGILE Conference on Geographic Information Science, Leuven, Belgium*.

Serrão, M., Rodrigues, J. M. F., Rodrigues, J. I., & Du Buf, J. M. H. (2012). Indoor localization and navigation for blind persons using visual landmarks and a GIS. *Procedia Computer Science*, *14*(Dsai), 65–73. http://doi.org/10.1016/j.procs.2012.10.008.

Strothotte, T., Petrie, H., Johnson, V., & Reichert, L. (1995). MoBIC : user needs and preliminary design for a mobility aid for blind and elderly travellers. *Computer*, *1*, 348–351.

Swobodzinski, M., & Raubal, M. (2009). An Indoor Routing Algorithm for the Blind : Development and Comparison to a Routing Algorithm for the Sighted. *International Journal of Geographical Information Science*, *23*(10), 1315–1343. http://doi.org/10.1080/13658810802421115.

Tröndle, M., Greenwood, S., Kirchberg, V., & Tschacher, W. (2014). An Integrative and Comprehensive Methodology for Studying Aesthetic Experience in the Field Merging Movement Tracking, Physiology, and Psychological Data. *Environment and Behavior*, *46*(1), 102–135.

Yaagoubi, R., Edwards, G., Badard, T., & Mostafavi, M. A. (2012). Enhancing the mental representations of space used by blind pedestrians, based on an image schemata model. *Cognitive Processing*, *13*(4), 333–347. http://doi.org/10.1007/s10339-012-0523-3.