

Planning Your Journey in Audio: Design and Evaluation of Auditory Route Overviews

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Auditory overviews of routes can provide routing and map information to blind users enabling them to preview route maps before embarking on a journey. This paper investigates the usefulness of a system designed to do this through a Preliminary Survey, followed by a Design Study to gather the design requirements, development of a prototype and evaluation through a Usability Study. The design is drawn in 2-stages with 8 audio designers and 8 potential blind users. The auditory route overview is sequential and automatically generated as integrated audio. It comprises auditory icons to represent points of interest, earcons for auditory brackets encapsulating repeating points of interest, and speech for directions. A prototype based on this design is developed and evaluated with 22 sighted and 8 blind participants. The software architecture of the prototype including the route information retrieval and mapping onto audio has been included. The findings show that both groups perform well in route reconstruction and recognition tasks. Moreover, the functional route information and auditory icons are effectively designed and useful in forming a mental model of the route, which improves over time. However, the design of auditory brackets needs further improvement and testing. At all stages of the system development, input has been acquired from the end-user population and the design is adapted accordingly.

CCS Concepts: • **Human-centered computing** → **HCI design and evaluation methods**; **Laboratory experiments**; **User studies**; **Accessibility design and evaluation methods**; **Accessibility technologies**.

Additional Key Words and Phrases: Blind navigation, user-led design, auditory route overviews, auditory display design

1 INTRODUCTION

Maps have always been central in supporting travellers to plan their journeys. As digital technology is becoming ubiquitous in the world, mapping has evolved and many different ways of using and interacting with maps have been developed. They can be found in mobile phones, satellite navigation systems and on computers in general. With easy access to these tools, travelling to unknown or far-off places has become easier for the general population. Often, sighted people plan their journeys before undertaking travel. This allows them to pick a route of their choice, reduces the overhead of wrongly taken turns, and gives them confidence in the route they are taking. However, since maps are typically a visual representation of the geographical world, they are only readily available to sighted people. The almost 44 Million blind people in the world [Burton et al. 2021] do not have easy access to these tools. Even though many applications have been designed to aid live navigation, there is little to no work on software that would provide a preview of the route.

This paper explores the need for a system for blind users that would enable them to access their desired routes before embarking upon them, as audio overviews. The research undertaken involves requirements investigation, development of a prototype and its usability testing. The designed system presents an overview of the route

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1936-7228/2022/4-ART \$15.00

<https://doi.org/10.1145/3531529>

information, including the form of the route, the distances and turns, as well as any points of interest (PoIs) along the way. As a preview system, it is designed to provide route knowledge of the journey. It is envisioned as an add-on system to existing navigational aids, purposefully designed to augment rather than replace them, with the goal to facilitate independent blind travel.

1.1 Auditory route overviews

An auditory route overview is an auditory display that provides users with information that would help them learn more about the route before embarking on the journey. In this project, it includes route information, such as direction, distances, points of interest, etc. as audio, utilising different audio design techniques and auditory cues. Some of the scenarios it could help in could be in deciding whether to make a journey or not, conveying length and complexity of the journey, getting familiar with the points of interest along the route and choosing between different possible routes.

1.2 Design approach

The work in this research follows a user-led approach. Every stage of the research process, including needs assessment, generation of requirements and the usability testing involved the target users. The feedback from one study informed the design and research of the next one, and each iteration of the design reflected users' choice. A system designed in this way can lead to better take-up by the users and reduce the chances of abandonment [Phillips and Zhao 1993]. The blind community has been using audio-based products for several decades now [Dunai et al. 2010; Meijer 1992; Wilson et al. 2007]. Therefore, in addition to being the users of the products, they also had expertise in the field, both in auditory display based systems and assistive maps, which informed their requirements and feedback, improving the system design.

1.3 Research questions:

The following questions were investigated in this paper.

RQ₁ : Is providing auditory overview of routes prior to walking considered useful by the blind community?

RQ₂ : What sort of route components and auditory design techniques can be used in such a route overview system?

RQ₃ : Are the chosen designs effective in representing route information?

RQ₄ : In what ways has the user-led design practices influenced the design of the system? Why was it chosen?

RQ₁ has been investigated primarily in the Preliminary Survey (Section 3), but also to a smaller extent in the subsequent Design Study (Section 4) and Usability Studies (Section 6). *RQ₂* has been investigated in the Design Study while *RQ₃* has been investigated in the Usability Study. *RQ₄* has been addressed through reflective analysis of the approach taken throughout this research work and captured in the Discussion section (Section 7).

1.4 Structure of the paper:

This paper is organised as follows: first, a review of related work and fields that contribute to building a foundation of knowledge is provided. Then, for the design process, a Preliminary Survey is described to investigate the requirements and the preferred application for auditory overviews according to blind individuals. This is followed by the Design Study which comprises two sessions. The Designer Workshop session includes workshops with expert designers to obtain insights into design techniques and guidelines for auditory route overviews. The User Feedback session includes the user perspectives and requirements from blind participants for these overviews. This section includes the study design, analysis of the data and discussion of the results for both sessions of the Design Study to draw the design guidelines. The next section deals with the development of a prototype.

It discusses the design decisions taken from the findings of the Preliminary Survey and the Design Study, the rationale behind them as well as an implementation. This is followed by evaluation through a Usability Study investigating how effectively the prototype auditory route overview communicates the route information to the users. It tests each design specification with both sighted and blind users to determine the usability of the prototype and the usefulness of the system. Finally, some limitations of the work and plans for the future are discussed. A pictorial representation of the research process is given in Figure 1.

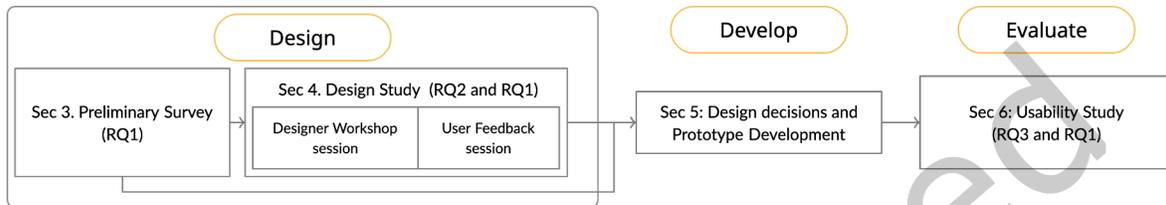


Fig. 1. Flowchart of the auditory route overview design process

A list of definitions and acronyms used in this manuscript can be found in Appendix A.

2 RELATED WORK

This section discusses the importance of auditory maps, their design guidelines and evaluation techniques, in the light of the literature. It also looks into the need for pre-planning tools and auditory overviews.

2.1 Accessible maps

Maps can be made accessible using tactile technology, audio or a combination of both. Many researchers have designed accessible maps using tactile displays [Holloway et al. 2018; Milo and Reiss 2017]. These can be static, like Braille on paper, vibratory, with mechanically-actuated pins to generate shapes and textures, or electro-tactile, using sophisticated electronic displays to provide interaction and dynamic haptic feedback [O’Sullivan et al. 2015]. However, they are not always feasible or easily available owing to hardware requirements, difficult layout, peoples’ lack of awareness about them, insufficient information in them and their patchy geographic coverage [Rowell and Ungar 2005]. One way to make them more user-friendly is to superimpose an interactive auditory display on the tactile display to to enhance the map information, as in [O’Sullivan et al. 2015; Yatani et al. 2012]. However, it still has some of the same disadvantages, where it is not readily available, it requires specialised hardware or production techniques and can not be readily modified or updated.

On the other hand, using only audio to provide map information is cheap and accessible, doesn’t require any specialised hardware and can be easily and quickly updated. Geographical map data can be transformed into an auditory display for blind users, for instance, in the TEAMs system [Loeliger and Stockman 2014]. Depending on the techniques used to transform and represent this information, the blind individual can then learn to interpret this audio input to extract meaningful geographical information. However, the representation of any information transformed to another domain must be effective and ergonomic [Lewis 2017]. The main disadvantages of using audio by itself, however, are the chances of cognitive overload [Kortum 2008, Chapter 5] and lack of kinesthetic input. Another issue is that map information is inherently spatial, whereas information conveyed in audio is perceived over time.

A comprehensive review of accessible maps can be found in Ducasse et al. [2018].

Auditory maps. Several researchers have used auditory displays for providing geographical information in their research, called auditory maps, such as [Heuten et al. 2007; Loeliger and Stockman 2014; Picinali et al. 2014; Pielot et al. 2007]. An auditory map is an aural representation of the visual, geographical features of a map. They are designed for blind individuals to access this information and, in most cases, interact with it, to aid independent travel. All of the projects mentioned present different ways of rendering map information to blind users. Auditory maps are either used passively to explore unknown areas or actively, as a navigation aid, to guide while travelling. For active navigation, there are a number of mechanical and electronic tools that have been developed, including [Dunai et al. 2010; Guerreiro et al. 2017; Wilson et al. 2007].

Similarly, exploration to acquire map information has been investigated by several researchers as well, including [Biggs et al. 2019; Heuten et al. 2007; Lahav et al. 2012; Loeliger and Stockman 2014; Pielot et al. 2007]. Pielot et al. [2007] designed auditory maps using a movable marker on a table top, encouraging users to explore the virtual space. Their system determined orientation through rotation of the tangible device, showing increased usability of an auditory map. Similarly, Heuten et al. [2007] used a torch metaphor whereby users could only hear objects within a particular radius. Both of these approaches encouraged exploration of the surrounding environment through which the user was presented with the various features in the area, their directions and relative distances. Both of these research projects designed their maps as auditory displays containing auditory icons (AIs) to represent different points of interests (PoIs), such as lakes, parks, etc. Their initial results showed that the participants were able to reproduce a sonified city map similar to the original one. Similarly, Biggs et al. [2019] developed a web-based auditory map prototype for exploration of a fixed virtual space, like a park. They used audio gaming conventions including sound markers and speech. The results of their work showed that the participants found their interface extremely easy to learn and navigate, and that they needed an interactive user interface to effectively learn about spatial properties and relationships between map features.

Loeliger and Stockman [2014] also developed an interactive audio map, called TEAMs (tutor for editable audio maps). The TEAMs system supported interactive exploration, as well as allowing a route to be set between any two locations. Their primary users were also blind. The system allowed them to virtually explore and navigate from the safety of their home, using 3D audio and synthetic speech. Their design used a combination of earcons, AIs and speech signals. To avoid the problem of overlapping sound models, the authors used AIs and earcons for completely separate purposes. Their results also showed that participants acquired detailed spatial knowledge and had a significantly improved wayfinding performance.

Connors et al. [2013] and Lahav et al. [2018] both encouraged exploration to gain knowledge of the surroundings by creating virtual environments and using a gaming setup. Connors et al. [2013] developed a virtual environment software called Audio-based Environment Simulator (AbES) to provide a training platform for route selection, based only on audio cues. Their experiment used a video game metaphor, where participants explore the inside of a building by moving around it. The information thus gathered allowed them to develop a spatial cognitive map of a large 3D space. They hypothesised that training on a virtual map would improve real world navigation skills in blind users. Their initial results show that the users were successful in gaining route knowledge and building a mental map through their system. Lahav et al. [2018] combined haptic and auditory feedback triggered by walking in a virtual environment to enable the development of a spatial map. They provided the haptic feedback using a Nintendo Wii Controller (Wiimote), which also acted as a pre-planning aid to explore virtual environments representing real spaces. Their results showed that 60% of the participants who explored the virtual environment using the controller were able to develop a map-based mental model as compared to 30% who did not conduct any a priori exploration. Thus, their findings also showed that prior exploration and collection of spatial information enhanced the ability of the participants to construct mental maps.

Guerreiro et al. [2017] combined active navigation and passive information gathering in their research. They created auditory overviews of partial routes to provide live navigation information, such as turn instructions and distances. They created overviews of the sections of a route, from one PoI to the next, which the users could

access while walking. The results from their experiments showed that most of their participants were able to create and maintain an accurate mental representation of both the sequential structure of the route and the approximate locations of the PoIs.

This paper combines the ideas from Connors et al. [2013]; Guerreiro et al. [2017]; Lahav et al. [2018] and Loeliger and Stockman [2014], to provide an auditory route overview between any two real world locations on a map for previewing and pre-planning purposes. The system allows for familiarisation, information gathering and strategic decision making for blind users to increase their apriori knowledge and confidence for independent blind travel.

2.2 Is there a need for pre-planning tools?

Several researchers have found that blind individuals are hesitant in undertaking journeys to unknown cities or places as the current technology does not provide any substantial support for them to gain a non-visual overview of the new place, its landmarks and geographic entities [Guerreiro et al. 2017; Heuten et al. 2007; Kitchin and Jacobson 1997; Lahav et al. 2012; Williams et al. 2013]. These are important cues for blind users as they rely heavily on them for navigation. Moreover, due to the sequential nature of routes, an error in one step can leave the person stranded [Thinus-Blanc and Gaunet 1997]. According to Clark-Carter et al. [1986], because of this lack of preview of their environment, blind users frequently adopt slower walking speeds. They state that electronic mobility aids can increase preview, and thus thinking time, providing confidence to the blind traveller.

Providing a preview of the route to be travelled can also enable the users to make travel decisions and familiarise themselves with the route features before embarking on their journey. Lahav et al. [2018] state that pre-planning aids can provide users with information before arrival in a space. These aids can be used in addition to the primary aids, such as the long cane and the guide dog, to support independent mobility. The previews can be delivered using verbal descriptions, tactile maps or screens, having physical models and digital audio [Lahav et al. 2018]. Clark-Carter et al. [1986] developed the Sonic Pathfinder, an electronic equivalent of the white cane, allowing varying levels of preview. As mentioned, their results found that the users confidence and hence walking speeds increased considerably while using it. Similarly, Hennig et al. [2017]'s experiments showed that having the availability of even a brief explanation beforehand was considered particularly important by the majority of their blind participants. Almost 70% of their 129 participants stated that they used the internet to plan and prepare for trips reinforcing the importance of the need for previews. Similarly, Yang et al. [2011], ran a set of interviews with blind people to show that providing general spatial awareness was the key to greater independence. Lahav et al. [2018] also showed an increase in the ability to create a mental map based on the map model of a real space when users had means to explore the space virtually before hand. Guerreiro et al. [2017]'s users also reported increased confidence after having previews of partial routes.

All of these projects show the importance of previewing and pre-planning tools for increasing the confidence and supporting independent travel of blind users.

2.3 Importance of overviews

Maps are composed of rich and varied information. Attempting to provide all of it together in a single auditory display could result in auditory overload [Kortum 2008, Chapter 5]. In his seminal paper, Shneiderman [1996] advocates the use of overviews. According to him, for presenting a large amount of data in an information-seeking operation, the first step can be to provide an overview, which can then be followed by zoom and filter and then details-on-demand. He argues that overviews allow users to conceptualise the information being presented. Along with several of his colleagues, Shneiderman has explored their uses in browsing hierarchies, finding connections in seemingly disparate events and presenting large-scale data like photo libraries. Zhao et al. [2008a,b] built on Shneiderman [1996]'s work and used auditory overviews for information seeking in geo-referenced data. They

found that the auditory overview successfully displayed patterns in the data and encouraged further exploration of areas of interest. Heuten et al. [2007] used a similar concept in their work, where the users could choose to zoom out of a location to get a "bird's eye view" of a geographical map as an auditory overview, or zoom in to get more detail. Thus, the overviews can be used to provide a quick, high level summary of the information, which may or may not lead to further exploration.

According to Stockman et al. [2013], auditory overviews have four general characteristics. They are comprehensive in either describing the entire collection of information or form a hierarchy of overviews to divide this into smaller parts. They provide a general understanding of the data in an abstract way, obscuring details and reducing complexity. They guide the user for navigation and finding the right direction. And finally, they expose the interrelationships in data as they provide a bird's eye-view of the whole picture. They have also been shown to encourage exploration of data, expose structure and separate key points from detail.

Providing route information as an auditory overview can serve to potentially make the users familiar with the route without going into the details. They can be built on Stockman et al. [2013]'s criteria, where they provide the entire route together as a preview in a high-level format, obscuring low-level details. They can also make the user aware of the different features on the route and the spatial relationships between them.

2.4 Design guidelines for accessible audio maps

Hennig et al. [2017] provide design guidelines and recommendations for developing accessible maps including providing a verbal description of the map content, the amount of information appropriate to be delivered in such a display, the order in which this information should be presented and the best ways of representing functional information, such as distance and direction.

Route information, in general, includes a sequence of steps to travel from one point to another, usually integrating some PoIs along the way [Kitchin and Jacobson 1997]. PoIs are fixed objects in specific locations on the route that can serve as way-points to help in orientation and localisation. They are an important element in route instructions as they increase the clarity of routes, resulting in more efficient and reliable navigation [Caduff and Timpf 2005]. According to them, having suitably described information of well-recognisable objects in the environment can make following routes much easier. Thus, including PoIs along with the functional form of the route information could improve the overview's effectiveness. They also stated that data presented as speech would have less of a learning curve while AIs create soundscapes that engage listeners and help form a mental map [Caduff and Timpf 2005].

2.5 Designing auditory displays

Auditory display is an overarching term that encompasses all systems where information is represented as sound [Letowski et al. 2001]. The information being represented, the sound being mapped and the end-user are all major factors in the design of auditory displays [Hermann et al. 2011, Chapter 1]. Different techniques are reported in literature to map information into sound, which is then presented to the user as an auditory display.

Auditory displays can be made up of a number of components, including speech and non-speech sounds, through a process called sonification [Hermann et al. 2011]. Sonification is accomplished by mapping represented relations in one domain, such as visual, to relations in an acoustic domain for the purposes of "interpreting, understanding, or communicating" them [Spagnol et al. 2016]. In this paper, the mapped data is converted to a time-ordered sequential audio data stream, as discussed by Hermann et al. [2011, Chapter 1].

During the design process, in order to reduce the learning curve and improve the usability of the sonification, the designers employ mappings which are intuitive and follow some logical relationship between the data values and the sound property or properties into which they are being mapped. There are a number of sound properties that can be used for this mapping process, including frequency, amplitude and tempo. Timbre, the harmonic

quality of a sound, is not a property that lends itself to this mapping, because it isn't ordinal, but sounds with different timbres might be used to represent different sources or channels in a sonification. In general, an auditory display may comprise any combination of speech and non-speech sounds [Heuten et al. 2007; Lahav et al. 2012; Loeliger and Stockman 2014; Wilson et al. 2007]. Some of the ways in which designers use them are discussed below.

2.5.1 Speech sounds. Speech sounds can be produced using both real audio recordings and synthetically produced text-to-speech. Synthetic speech has the advantage that it can be generated dynamically while the system is active. Moreover, blind users are quite accustomed to it, through their use of screen readers and other accessibility software, thus reducing or eliminating the learning phase. Many applications, like SpaceSense [Yatani et al. 2012], provide all map information using speech. They provide step-by-step navigation, road names as well as details of 20 different PoIs using dynamically generated synthetic speech. Similarly, Guerreiro et al. [2017] also used speech to present map information. On the other hand, Loeliger and Stockman [2014] used speech sounds to represent names of roads only.

2.5.2 Non-speech sounds. According to Brewster, presenting information in speech can be slow and in order to be understood, it must be played in its entirety and many words may have to be heard before a message can be comprehended. On the other hand, non-speech sounds are shorter and therefore more rapidly heard. Moreover, just as the pictorial icon is universal, its audio equivalent, known as an auditory icon, doesn't need to have its meaning translated to different languages to be understood [Brewster 1994]. Non-speech sounds include AIs and earcons, which can be used independently or mixed together to represent a scene.

Auditory Icons (AIs). AIs are representative sounds that appear as “caricatures of naturally occurring sounds”, such as bumping or crashing [Gaver 1986]. They utilise real, everyday, iconic sounds that are used for the purpose they represent, such as church bells representing a church, leading to a “quick and effortless identification and interpretation” of the underlying data [Kortum 2008, Chapter 5]. This makes the representation intuitive and the learning minimal. In a navigation application, AIs can be used to represent types of locations such as a bar, cafe or park [Loeliger and Stockman 2014]. Sometimes, however, such natural mappings are not possible, for instance, due to the nature of the object being represented. For instance, there are no “naturally occurring sounds that would be generally recognised as representing hospitals. In such scenarios, AIs can be designed using metaphors, cliches or genre sounds [Buxton et al. 1994]. For example, using the sound of a pumping heart as a symbol for hospitals, particularly where there is an opportunity to train users or provide a reminder of the mappings used. Another factor to consider while designing AIs is their universality. For example, in some countries a safe crossing for pedestrians is indicated by a repetitive beeping sound that stops when the road is no longer safe to cross. Whereas, in other countries, the same information is given by “click” like sounds, with the pause between clicks becoming shorter over time, indicating there is less time until the road becomes open to traffic again.

Earcons. Earcons are musical motives grouped together as a family to represent similar meaning sounds [Blattner et al. 1989]. They can be designed using concatenation and/or concurrency, to synthesise more complex messages from simple building blocks [Kortum 2008].

When a sonified signal is presented to the user, they must decode and integrate the presented information into an object-based representation [Brown et al. 2015]. This process is time consuming, stressful and hard. First, the users have to learn the mapping scheme by focusing and repeating the task multiple times and then try to apply it within the specific context of use. However, gradually, as users gain experience, the process becomes more natural [Maidenbaum et al. 2013], [Kortum 2008, Chapter 5]. If the representations are designed to make the mapping is obvious and intuitive to the users, the learning process can be greatly reduced [Hermann et al. 2011, Chapter 14]. For example, some good things about the theme park example described earlier, due to Brewster [Hermann et al. 2011, Chapter 14] are as follows: a) Each type of ride is mapped to an instrument whose timbre is

very different from the instruments used to depict other rides; b) The number of notes being used to represent a monetary amount works because both elements involve quantitative values; c) The level of excitement to pitch mapping uses the analogy that a more exciting ride is represented by notes of a higher pitch.

If designed correctly, these audio components can make the system lively and interesting as well as reduce the learning curve. Conversely, overloading the user's senses with them, individually or in combination, might lead to an unpleasant and distracting auditory display [Loeliger and Stockman 2014]. This is a major quality of a good sonification algorithm and a characteristic that should be tested when developing auditory displays.

Guerreiro et al. [2017] built their accessible maps, including PoIs, using speech. They used sound cues to provide feedback that the phone's rotation is oriented with the route to mimic turning. Heuten et al. [2007] and Pielot et al. [2007] used spatialised AIs based on everyday sounds to represent the landscape. Connors et al. [2013] used synthetic speech to provide location, orientation and heading of the player, as well as obstacles, like doors. They used sound cues for giving the location of objects in the surroundings, like jewels and monsters, in their game environment. Orientation was given as cardinal compass headings and distance cues were provided based on modulating sound intensity. All sounds were spatialised. Lahav et al. [2012] used a combination of audio and haptic feedback. They used different tones to represent different objects. These tones change with the distance to the object and a constant rumble is triggered upon collision. Pressing buttons produces spoken distance and the name of the object detected as well. Loeliger and Stockman [2014] created an auditory route display using both synthetic speech and non-speech sounds, including AIs and earcons. To ensure that mixing the different audio forms did not cause confusing or annoyance, they took three steps. First, they created a ducking effect by fading all the sounds out before the next began. Secondly, they designed the earcons and AIs to be completely separate functions, with AIs representing PoIs and earcons presenting the movement through the route. Finally, they designed the earcons such as to reduce the chances of masking the AIs. The PoIs were also announced using speech.

2.6 Accessible map evaluation

The following section takes a look at the methods used in the literature both for evaluation of the representation of maps as well as auditory displays. Both of these inform the evaluation methods used in this work.

2.6.1 Evaluating the map representations. Kitchin and Jacobson [Kitchin and Jacobson 1997] divided the evaluation for route based tasks into three categories: physically retracing the route, estimating the distances between the start and end nodes or between the individual segments of the route and estimating the directions between them. Then, they combined the second and third evaluation categories into one reconstruction task, evaluating both distances and directions. Yatani et al. [2012] and Guerreiro et al. [2017] used reconstruction tasks to evaluate their route representation systems. Yatani et al. [2012] used acrylic pieces for reconstruction task to evaluate the differences between their auditory and tactile representations of the route. They formulated metrics to determine errors in route accuracy, by comparing the size and shape, directions, and distances of the reconstructed route to the original. They recorded the training time and the reconstruction time of participants as well. Guerreiro et al. [2017] used both retracing and reconstruction tasks for evaluating the efficacy of their auditory route navigation application. For the reconstruction tasks they used a set of LEGO blocks and base plates. They modified the error metrics used by Yatani et al. [2012] to include PoI recognition and placement errors. For the retrace task, they defined a 5-point scaled accuracy weighted for distance, ranking from "high" accuracy given a value of 1 for an error rate of five or less steps to "zero accuracy" given a value of 0 for incorrect turns or missing a PoI. The times for both tasks were recorded as well. According to Yatani et al. [2012], exploratory tasks before travelling were better evaluated using reconstruction or recall tasks in laboratory studies rather than retracing tasks in the physical world. They were also considered safer as they did not require blind participants to walk over unknown routes.

2.6.2 Evaluating the auditory display. It is crucial to evaluate the design of the auditory display as well as its components. According to both Bonebright and Flowers [Hermann et al. 2011, Chapter 6] and Peres et al. [Kortum 2008, Chapter 5], the evaluation of auditory display design should start in the formative stages, with testing done iteratively at every step. Bonebright and Flowers state that "it is an extreme waste of time and other resources to finish an auditory display and only then have the target audience attempt to use it".

Peres et al. suggest using listening tests, contextual mock-ups and prototypes of the auditory interfaces to test the design efficacy and make modifications in an iterative cycle. They encourage the use of rapid prototyping techniques such as the Wizard of Oz and the use of sound libraries from the internet to create a quick, concept prototype for formative testing. Both Hermann et al. [2011, Chapter 5] and Kortum [2008, Chapter 6] suggest that the evaluations should be done both in-lab to test the audio and in-context to ensure that ambient noise doesn't overlap the display. Finally, the participants in the evaluations should be from the same population as the target users of the application. The data captured should include completion time of the evaluation, identification tasks measuring the accuracy and reaction time for correct identification, attribute ratings like pleasant, hard, etc and the ease of differentiation between the different sounds used.

2.7 Summary

There is evidence in the literature that having a non-visual overview of routes before travelling is important to the blind population. Several researchers have developed audio maps as an auditory display using speech and non-speech sounds, including the use of AIs and earcons. These displays can be designed following guidelines from literature, such as providing a verbal description of the map content, the amount of information appropriate, the order in which it is presented and the best representations of the functional information, such as distance and direction. Evaluation of the route based information has been done using reconstruction and recognition tasks.

To our knowledge, no significant work has been done on developing auditory routes overviews for previewing routes, and strategic planning or preparation of a journey. The following sections describe our research investigating the requirements for the presentation and content of route overviews for the blind population. We also seek to develop design rationale for creating a priori auditory route overviews and evaluating them for their effectiveness in providing this information. Such a system may support independent travel of blind users by increasing route familiarity, providing an idea of the landscape around it and helping them make strategic decisions regarding alternate routes from the safety of their homes or offices. This, in turn, could make unseen travel less stressful and cognitively less demanding, enabling the individual to focus on navigation and potential hazards.

3 PRELIMINARY SURVEY

The first step in designing a system that was both useful and usable by blind participants was to gather information about their requirements and preferences.

A preliminary survey was conducted with blind users to investigate RQ_1 and get an initial understanding of the requirements for auditory overviews. The responses gave an insight into the applications that could benefit from having overviews and some initial design criteria as required by people with visual impairments [Aziz et al. 2019].

The Preliminary Survey investigated whether the auditory overviews had any value for the blind community or not. Furthermore, to understand the requirement for route overviews, the survey also requested the participants to choose the application that they thought would benefit the most from having auditory overviews.

3.1 Participants

Fifteen blind individuals, denoted using the prefix P_{PS} , participated in the survey (5 female and 10 male; aged between 17 and 72) and were recruited from target groups on social media. All participants self-reported that they were experienced in using screen readers and other assistive technologies, with twelve being regular screen reader users and three using screen magnification.

All three studies, the Preliminary Survey, the Design Study (Section 4) and the Usability Study (Section 5), were approved by the Research Ethics Committee. All participants were informed about the nature of the experiments and data (observations, audio and video) to be collected both with the calls for participation and before they started each study. They signed written consent forms explaining the nature of the studies and making clear that they could withdraw at any time with no penalty to themselves, in line with the principle of informed consent [Lazar et al. 2015].

3.2 Survey design

To introduce the participants to the concept of auditory overviews, the first part of the survey presented two non-speech based auditory weather forecast overviews, taken from [Hermann et al. 2011]. The introduction was followed by four questions. These related to the importance of overviews, target applications, length of the overviews and type of information presented. Questions 1 and 2 were rating questions while 3 and 4 were open-ended. The participants were informed that the purpose of the survey was to gain a better understanding of which applications would benefit from having auditory overviews and how useful they could be. The questions posed to the participants in the survey are included in Appendix B.

3.3 Results and findings

The data gathered in the overviews was analysed using statistical techniques, including mean and standard deviation to determine the central tendency and dispersion of the data as well as Wilcoxon signed ranks test to compare ratings between pairs of options. These tests led to the following findings:

Auditory overviews are useful and important. The first question asked the participants to rate the usefulness and importance of auditory overviews. The results showed that the participants viewed overviews favourably. Of the fourteen participants who responded to this question, ten gave an average score of 4 out of 5, three responded with a yes, and one stated that they had no prior experience with them ($M=4.14$, $SD=0.86$).

Route overviews are significantly more preferable. In the next question, the participants were asked to rate six applications that might benefit from auditory overviews. The participants rated the importance of overviews of routes at 4.8 out of 5 on average. The ratings for the remaining applications were between 3.2 and 4. Figure 2 shows the average ratings given by the participants for each application.

The graph shows that the participants considered that all these applications could benefit from having auditory overviews. However, the ratings for overviews of routes were higher than other applications. Non-parametric Wilcoxon signed ranks tests ($p=0.05$) were conducted to compare them with the remaining applications ratings. The tests showed a statistically significant difference in the scores for auditory overviews for routes and the rest of the applications (higher values of all z-scores and all p-values < 0.05) as shown in Table 1. Thus, among the six applications suggested, the participants considered having auditory overviews for routes to be more useful.

Duration depends on the content being represented. The next question in the survey was regarding the length of the overview. According to literature [Zhao et al. 2008a], an auditory display that is too long will have a larger cognitive load. In their paper, they suggested that an auditory display of up to 10 seconds would be optimal for their auditory overview application. However, the participants of this study indicated that for route-based applications, this duration might be too short to provide any substantial information. Fourteen of them gave an

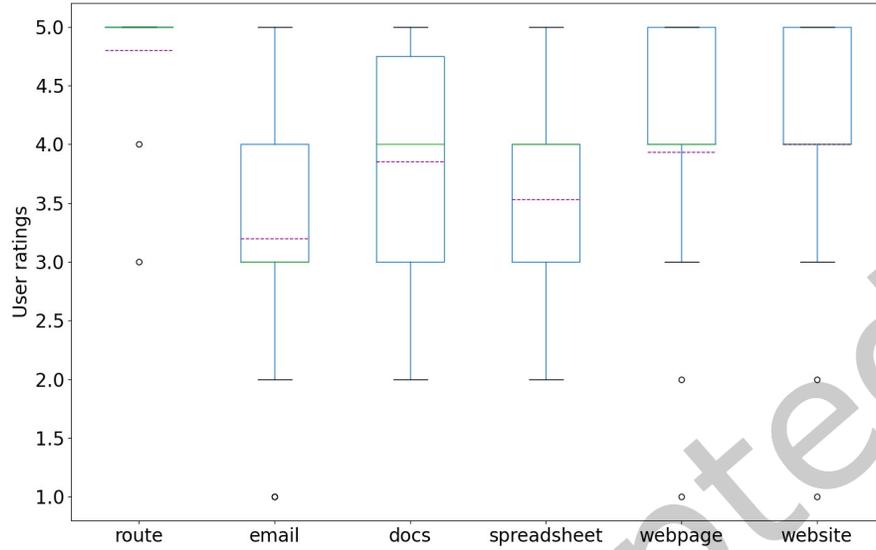


Fig. 2. Preference for auditory overviews of different applications on a scale of 1 to 5 with 5 being most preferred. The dashed line indicates the average values.

average rating of 3.14 out of 5 in favour of a 10s long duration, while one responded as "not sure". Participants, P_{PS3} , P_{PS5} and P_{PS9} thought the duration should be longer, P_{PS6} thought the overviews should be "as long as the information they need to convey" while P_{PS1} and P_{PS10} believed they should be customisable.

Techniques depend on the content being represented. The final question was regarding the constituent content of the auditory display. The participants rated speech-based overviews 4.5 out of 5 on average, non-speech based overviews 2.4 out of 5, while a combination of the two was rated at 4.2 out of 5. Finally, choosing the technique based on the application and context was rated as 4.8 out of 5. Thus, the participants preferred having content chosen on the basis of the application and context, as shown in Figure 3, however, they showed partiality towards speech-based information too.

Table 1. Wilcoxon signed ranks tests for significant difference between ratings of different applications

	Z-stat	Sig (two tailed)
route-email	-3.097	0.002
route-document	-2.412	0.016
route-spreadsheet	-3.096	0.002
route-webpage	-2.228	0.026
route-website	-2.064.	0.039

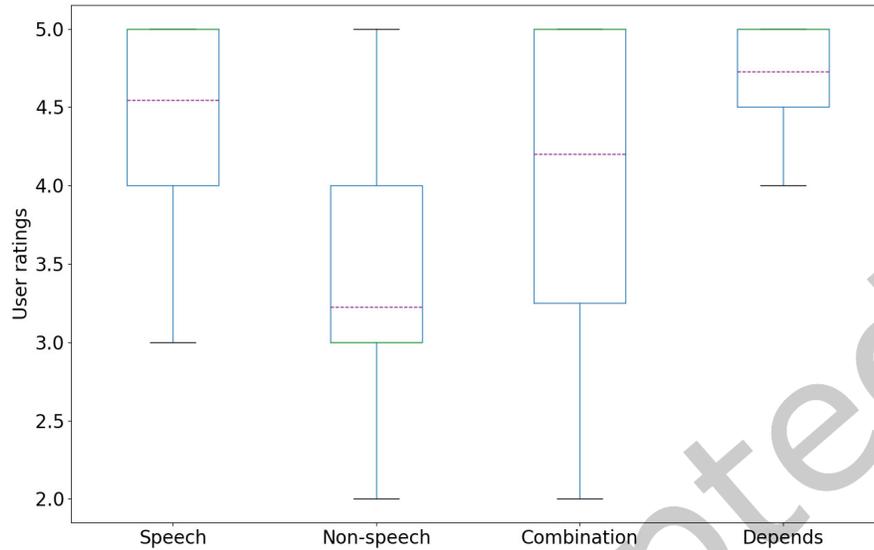


Fig. 3. Preference between having speech, non-speech, a combination of speech and non-speech, and deciding representation based on application/ and context in the auditory display on a scale of 1 to 5 with 5 being most preferred. The dashed line indicates the average values.

3.4 Discussion

The survey was conducted to learn about the requirements of the blind individuals, including preferred applications for overviews and the type of audio to present them. The findings showed that the users were keen on almost all of the applications that were suggested, showing a requirement for audio overviews for blind users and a gap in their availability. They also showed a significant preference towards route overviews. A reason for this could be the opportunity of added independence and control over their travel. This was a huge motivation in choosing this as the target application.

With regards to the time duration, it seemed that the participants had a mixed response. Majority of the participants disagreed with the 10s limit. They were of the opinion that duration of the AD should either be dependent on the information it is carrying or should be customisable for the user.

The participants thought that the type of audio used to design the overviews would also depend greatly on the application, as can be seen from Figure 3. Among the given choices, i.e. speech, non-speech and an AD with a combination of both of these, a clear partiality towards speech based ADs could be seen followed by combination AD. Participants were not keen on having a completely non-speech based system, possibly because they were accustomed to using speech based access technology, like screen readers.

4 DESIGN STUDY

After analysing the results of the survey and gathering a preliminary overview of requirements, a two-part study was arranged to build design perspectives and investigate RQ_2 . In the first part, the Designer Workshop session, a workshop was held with audio and/or design experts. This population was chosen to capture their knowledge in relation to design and audio and to discuss the design process. Some of the designs produced were then chosen for evaluation by blind individuals in the second part of the study, named the User Feedback session. Feedback

Table 2. Demographics of expert designers for the Design Study

ID	Age	Gender	Experience with audio/design
P_{DS1}	39 years	M	14 years
P_{DS2}	29 years	M	6 years
P_{DS3}	33 years	F	7 years
P_{DS4}	29 years	M	12 years
P_{DS5}	23 years	F	3 years
P_{DS6}	36 years	M	20 years
P_{DS7}	29 years	F	8 years
P_{DS8}	26 years	F	5 years

from the end-users was important to ensure the usability and usefulness of the designs. Thus, even though the two populations of participants did not overlap for the study, the input of expert participants into the design guidelines and feedback from the end-users on those guidelines created a cycle of co-operative inquiry [Bergold and Thomas 2012].

4.1 Objective

The objective of the Design Study was to generate initial auditory route overview designs and gather the views of potential blind users in response to those designs. It was devised employing an expert designer population and a blind user population. The designer population was engaged in an ideation workshop, followed by semi-structured interviews, to investigate what they took into consideration while designing auditory displays for route overviews. The techniques employed were also noted and discussed. The user population gave their feedback on the ideas and designs as well as techniques of the designer population. Other factors essential to the success of auditory route overviews were also investigated [Aziz et al. 2019].

4.2 Ethics

The study was approved by the (blinded for review) Research Ethics Committee. All participants were informed about the nature of the experiment and data (observations, audio and video) to be collected. They signed a consent form explaining the study design and made clear that they could withdraw at any time with no penalty to themselves.

4.3 Designer Workshop

4.3.1 Participants. Eight participants, denoted using the prefix P_{DS} , were recruited (Table 2) to participate in the workshops. They were chosen individually because of their domain knowledge through expert sampling from the researcher's school and invited by email. All participants were PhD students. Six of them had over 5 years of experience working with audio designing while the remaining two were working in design and HCI. The participants were given electronic copies of the sample routes (example in Figure 4) from Open Street Maps¹ (OSM) to design auditory route overviews. During the design process, they were encouraged to ask questions and think-aloud. It was fully explained that they were part of a targeted user-group and their opinions were important to the iterative design process.

¹<http://www.openstreetmaps.org>

4.3.2 Study design. The Designer Workshop session consisted of five 1-1.5 hour long single-session workshops to gather design perspectives. Each workshop session comprised two parts. The first part was the design process to design and evaluate the auditory route overviews and the second part was end-of-study interviews to discuss the design process. It was held in pairs for all participants, except P_{DS7} and P_{DS8} (due to logistic reasons) and on separate days for each pair of participants.

The participants were given 30 minutes to complete the design process followed by the interview. The interview questions were related to the design process and focused on the design ideas and techniques. The predetermined questions included:

- (1) Can you discuss your design procedure?
- (2) What features of the route did you consider essential to represent?
- (3) What techniques did you use to represent route features in audio?
- (4) What were your main considerations?

4.3.3 Materials. For the design process, two routes were chosen on OSM, as shown in Figure 4 and assigned to each participant. The choice was made based on several features, including length of the route, number of turns and PoIs along it. They were provided to the participants through the OSM software several days before the start of the study, along with the initial communication regarding the study design during recruitment. The participants were requested to examine their routes before coming to the workshop, and design an auditory display for it during the workshop, individually, using any resources on-line and any audio editing software of their choice. They were asked to use their own machines and install the software beforehand. The participants

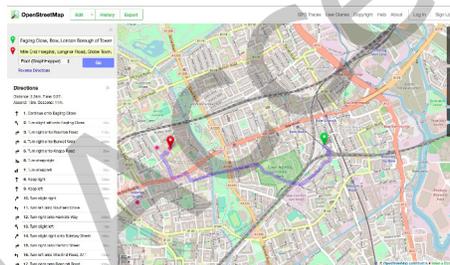


Fig. 4. Example route for the Designer Workshop

were encouraged to discuss their design processes and evaluate each other's designs at the end as well. All of this information was captured in audio recordings and later transcribed manually by the first author to be considered during the thematic analysis.

4.3.4 Findings from the Designer Workshop session. A thematic analysis of the data was conducted by the first author, with 50% of the themes checked by the second author, using an iterative, inductive approach to identify themes and sub-themes (Figure 5) discussed by the participants, as explained by Braun and Clarke [2006]. Data was investigated semantically based on a theoretical approach to determine design requirements. The data was analysed in a number of ways, including frequently occurring responses or ideas, acknowledging stress words, colour coding similar topics and comparing responses between participants. The data was investigated in a mixed manner with both semantic and latent themes. At the end of the standard 6-phase process of analysis [Braun and Clarke 2006], four themes emerged from the data: content, techniques, quality and training, as shown in Figure 5. These themes encompassed the designers' perspective on the design of an auditory display for route overviews including the techniques used to design them, their content and the qualities it should possess.

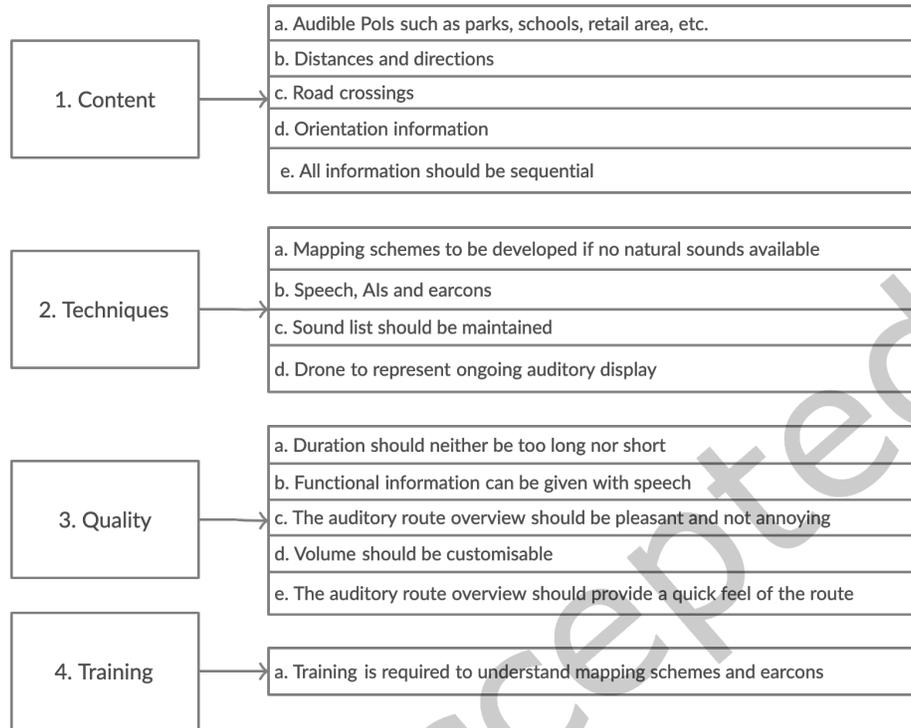


Fig. 5. Themes that emerged from applying a thematic analysis to the Designer Workshop

Several design parameters were presented regarding the content, techniques and quality of auditory route overviews, shown in Figure 5. The participants discussed different features such as distance, direction, orientation, road crossings etc. that make up the content of the auditory display, and discussed the resulting design implications. A brief discussion of these findings follows.

Design strategy. According to the participating designers, the auditory display for route overview should contain audible features[1.a.] such as landscapes and landmarks. This would include permanent features like parks, train stations, shopping areas, etc as well as temporary features like traffic, etc. which may not always be present. While all participants had their own strategies to design the auditory maps, seven out of eight started by looking for AIs that represented "[P_{DS1}] landmarks that would be in some way audible". P_{DS1} , P_{DS5} and P_{DS7} designed an audio walk by placing the chosen icons chronologically in a sequence[1.e.]. P_{DS1} and P_{DS6} panned them left and right to show which side of the route the PoIs were situated at[1.b.]. P_{DS1} then wanted to provide "turning [instructions] in relation to those sounds". For directions[1.b.], the participants used different representation techniques including speech, earcons, and panning. P_{DS4} overlaid speech on an earcon-based representation of the path. They mapped out the route using "different pitches for different directions and different panning,[a] central pitch for move forward and longer or shorter notes [to show] whether move forward for a long time or move forward just a few steps". P_{DS1} represented distance as "gaps in time". P_{DS2} stressed having clear directions, so they opted for using speech. They used the words "left" and "right" and then stretched them proportional to each leg of the route following each turn "like right right left leeeft right right". In a similar

manner, P_{DS8} designed AIs for PoIs covering greater distance to be longer. P_{DS6} panned an earcon from left to right to represent a turn. They moved a "percussive ... beep-beep-beep" sound towards the direction of the turn, kept it there for two beats and brought it back to the centre. Thus, distances were either represented by varying the length of the audio-object or the duration between them. Orientation[1.d.] was another factor that was discussed. They thought it was necessary to give orientation information in a clear, coherent manner to give starting reference and then later guidance through the rest of the route. P_{DS3} suggested that "street names make position and orientation more specific". Finally, it was suggested that road crossings[1.c.] should be clearly indicated, for example, using the size of road information to imply type of crossing [P_{DS8}]. Participant P_{DS6} and P_{DS7} also suggested to "[P_{DS6}] make it [the auditory route overview] as fun [pleasant and enjoyable][3.c.] as possible".

Techniques. The participants used different mapping schemes[2.a.] to represent route information. These include mapping approximate distance through time gaps as well as traffic density to sound amplitude. Similarly, road size was mapped by the number of cars sound and mapping roads with busy sounds and parks with quieter ones. Speech[2.b.] was considered an effective technique for providing important information as it would be "[P_{DS1}] easiest to understand" and "[P_{DS2}] very clear". This is in line with the findings of the preliminary survey (Section 2), in which speech based content was preferred. All participants except P_{DS1} , P_{DS4} , and P_{DS6} used speech to represent functional route information[3.b.]. Other techniques used were AIs and earcons[2.a.]. For instance, P_{DS4} used kick drums sounds to represent major road crossings[1.c.]. All participants except P_{DS2} used AIs in their designs. Participants P_{DS1} , P_{DS6} and P_{DS8} suggested to "[P_{DS}]6 to have a sound sync list[2.c.]" for any useful auditory landmark for a quick look-up. Finally, P_{DS6} and P_{DS7} added footsteps as a drone[2.d.] to show movement through the route.

Level of detail and duration. The participants discussed the trade-off between the quantity of information and the length of the auditory display. They noted that an overview should be short, but clear and accurate[3.a.]. P_{DS6} suggested to "give the users the ability to customise the amount of information[3.d.] they want to receive". Three participants, P_{DS1} , P_{DS6} , and P_{DS7} advised using abstract representations to provide a quick feel of the route[3.e.] i.e., using AIs and earcons to represent route features. For example, P_{DS7} used duck sounds to represent a canal and crow sounds for the cemetery.

Training. Some participants considered it important to train[4.a.] the users to understand the design of the auditory route overviews. P_{DS1} stated that training would increase familiarity with the system, and hence, may reduce learning time and error rate and the users won't "face the problem of listening to it 10 times" to understand the route.

4.4 User Feedback session

4.4.1 Methods and materials. The outcomes of the Designer Workshop session were assessed by blind participants in the User Feedback session of the design process. The purpose was to gather feedback as well as extract user requirements for an auditory display giving overview of routes. The study was done remotely, via emails. Three of the designed auditory route overviews from the Designer Workshop session were chosen to present to blind participants, along with a survey questionnaire. The rationale for the choice of route designs and details of each of the designs is given in Section 4.4.3.

The questions were guided by the discussions in both the Preliminary Survey (Section 3) and the Designer Workshop session and focused mostly on the content and quality of the design. The majority of questions were open-ended to encourage discussion of ideas and preferences.

Table 3. Demographics of blind users for the Design Study

ID	Gender	Age	Sight category	Onset of sight loss	Experience with assistive tech
P_{FS1}	M	55 years	Totally blind	Since birth	40 years
P_{FS2}	M	25 years	Totally blind	Since birth	Over 20 years
P_{FS3}	F	-	-	-	-
P_{FS4}	F	35-44 years	Severely sight impaired	Since childhood	-
P_{FS5}	M	40 years	Totally blind	Since birth	Over 30 years
P_{FS6}	F	52 years	Totally blind	22 years	16 years
P_{FS7}	F	31 years	-	-	8 years
P_{FS8}	M	57 years	Totally blind	26 years	26 years

4.4.2 Participants. Eight blind participants, denoted using the prefix P_{FS} , were recruited for the online study through social media. Two out of these, P_{FS1} and P_{FS6} participated in the Preliminary Survey (Section 3) as well, where they are referred to as P_{PS1} and P_{PS8} . The details of the participants are given in Table 3. Similar to the Designer Workshop session, the participants were told that their opinions were important to the design process and encouraged to give their responses in detail.

4.4.3 Details of sample auditory route overviews used in the study. Three out of the eight designs from the Designer Workshop session were chosen for the User Feedback session. They were chosen on the basis of the variety in their techniques and content. They included examples of all the design techniques used by the designers as well as all the route features included in the route designs produced by them. The designs were distributed as audio files along with the questionnaire in textual form (Appendix E) via email, as preferred by the participants. These designs are referred to as sample designs henceforth.

They have also been attached as supplementary material with the paper (Appendix E). The details of these designs are given below:

Design1: The overview was 13 seconds long. The designer used speech to relay distance, directions and PoIs. Then, they superimposed a panned beeping earcon on this speech to reinforce the forward and turn directions. For example, if the speech said "forward then second left", the earcon beeped once in the centre and then panned left and beeped twice, to show that it was the second left turn.

Design2: The second design was 1 minute and 22 seconds long. It consisted only of AIs to represent PoIs such as train station, park and canal. The designer panned these sounds to show the location of the PoI.

Design3: The third design was forty seconds long. The designer used speech to represent distance, directions, and street names, and AIs to represent PoIs.

4.4.4 Questionnaire. The questionnaire (included in Appendix C) consisted of eleven questions, focusing on the content of the ADs as well as their quality. For example, question 1 asked about earcons as the content of the AD and their clarity as the quality. Most of the questions were open-ended, with the aim of obtaining detailed responses. However, two questions, questions 8 and 9, required ranking. These questions were designed to analyse the effect of complexity and duration on understanding and retention of the route information. Both questions investigated the understanding and retention of the auditory routes. Question 8 was related to the difficulty level of the AD and was designed to get a concrete measure of how the users would evaluate the overlaying audio

content. Question 9 was about the effect of length of the audio to gather their perspectives on duration of the ADs and its effect on understanding and retention. The responses from the feedback were compared to those from the Preliminary Survey (Section 3) and the Designer Workshop session. They were also encouraged to add further comments wherever they felt comfortable.

The participants were asked to rate these properties on a scale of 0 to 10. Semantic labels, shown in Table 4, were created for the rating scale. The table runs from left to right, with the left hand side having smaller value, i.e., easy and short. For example, for question 8, 0 stands for extremely easy while 10 stands for extremely hard. The same convention is followed in question 9, with 0 being extremely short and 10 being extremely long. This scale was established later during analysis and was not provided to the participants.

Table 4. Semantic labels for the rating scale

0	1	2	3	4	5	6	7	8	9	10
extremely	very	moderately	relatively	slightly	neither	slightly	relatively	moderately	very	extremely

4.4.5 *Findings of the User Feedback session.* The analysis of the qualitative and quantitative feedback on the sample designs is presented below.

Quantitative analysis

The rounded mean of the participants' ratings for both the difficulty level in question 8 and length of design in question 9 was calculated, as shown in Table 5. The average rating, standard deviation and the corresponding semantic description for both the questions are given in the tables. A histogram showing the length and difficulty ratings of the three different auditory route overview designs is also given in Figure 6.

Table 5. Average participants' ratings for questions 8 and 9

1. Difficulty level of the design				2. Length of the design			
Design	Av rating	SD	Semantic description	Design	Av rating	SD	Semantic description
Design1	8	2.06	Moderately hard	Design1	3	3.77	Relatively short
Design2	9	1.89	Very hard	Design2	7	2.50	Relatively long
Design3	2	1.28	Moderately easy	Design3	5	1	Neither short nor long

A short description of the contents and duration of the three designs from the perspective of these two variables is given below to help understand and compare the results of these questions:

- Design1 comprised earcons and synthetic speech and was 13 seconds long.
- Design2 comprised AIs only, representing the landscape and PoIs through the route. It was 1 minute and 22 seconds long.
- Design3 consisted of synthetic speech and AIs integrated together. It was 40 seconds long.

For Question 8, the participants' average rating for Design1 was 8. Comparing that to Table 4, the corresponding semantic description would be "moderately hard". Thus, we can assume that the participants found Design1, having a combination of earcons and synthetic speech, moderately hard to understand and retain. For Design2, the average difficulty rating was 9, which corresponds to "very hard". Design2 comprised only AIs with no earcons or speech. Finally, for Design 3, the average rating was 2, corresponding to moderately easy. Design 3 comprised speech and AIs but had no earcons.

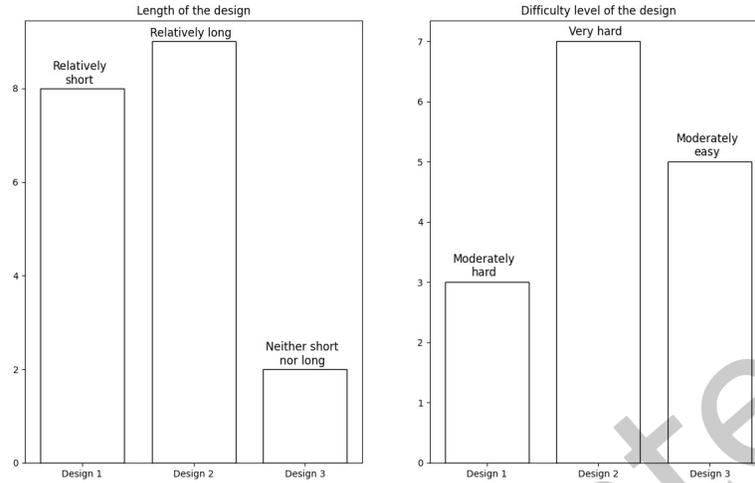


Fig. 6. Histogram showing the length and difficulty ratings of the three different auditory route overview designs. (a) left side: Length of the designs (b) right side: Difficulty of the designs

For Question 9, the participants' average rating for Design1 was 3. Comparing this to Table 4, the corresponding semantic description would be "relatively short". For Design2, the average rating was 7, which corresponds to "relatively long". Finally, Design 3, at 40 seconds long, had an average rating of 5 corresponding to "neither short nor long".

Thematic analysis

A thematic analysis of the user feedback data was conducted by the first author, with 50% of the themes checked by the second author, using an iterative, inductive approach to identify themes and sub-themes discussed by the participants, similar to the Designer Workshop session. Three themes emerged from the data: integrated audio (AIs, earcons and speech), customisation and training. They encompassed the designers' perspective on the design of an auditory display for route overviews. A brief discussion of these findings follows.

Integrated Audio. Participants preferred to be presented with functional route information, such as distances and directions, as speech[7.a.]. Five out of the eight participants stressed the importance of speech for clear understanding of the route. Four participants wanted to modify the volume or speed of the speech[7.c.] used in the sample designs. P_{FS2} wanted "a slower setting on the speech engine, or a different engine" while P_{FS1} wanted non-speech audio to be at half the volume of the speech[8.c.]. P_{FS5} considered having "a couple [of] different modes" where they could access information "based on preference". Moreover, three participants, P_{FS3} , P_{FS4} and P_{FS5} suggested that street names[7.b.] should also be provided as they were important orientation information for blind people .

PoIs are an important route feature, providing localisation as well as a feel of the landscape. All three sample designs included PoIs. Designs2 and 3 presented them through AIs and Design1 as speech. Three participants, P_{FS2} , P_{FS4} and P_{FS5} , stated that knowing the PoIs would be useful to their journey, "[P_{FS4}] particularly in unfamiliar places". However, none of the participants liked their presentation in Design2, which consisted only of

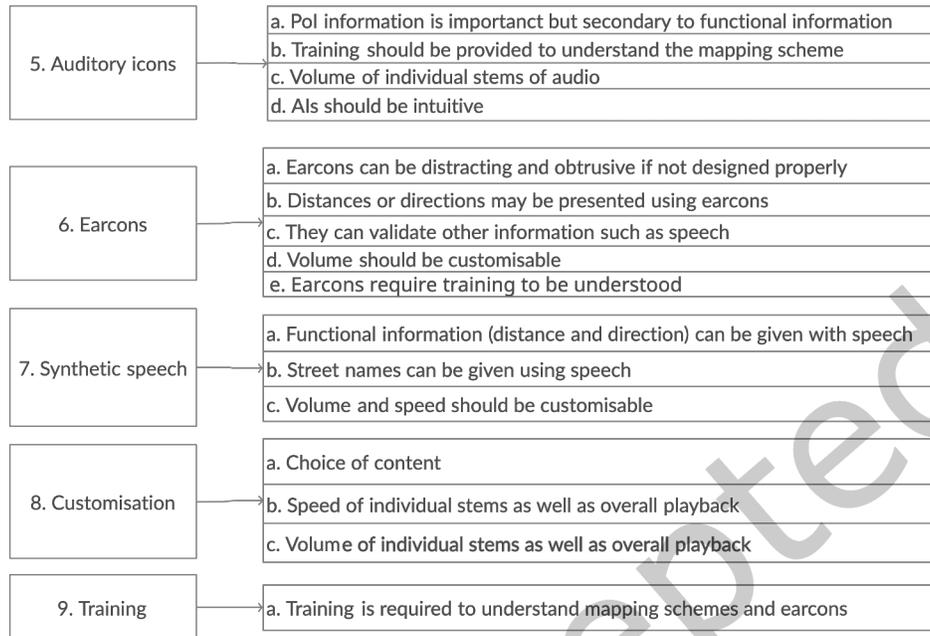


Fig. 7. Themes that emerged from applying a thematic analysis to User Feedback session

the PoIs. They gave it an average rating of 9.2 out of 10 for difficulty level of the design, with 10 being very hard, in terms of understanding and retaining the information. On the other hand, Design3, with integrated speech and AI, got an average rating of 1.75, showing that it was very easy to understand. Thus, the participants felt that PoIs by themselves were secondary to the functional information[5.a.]. On the other hand, an integrated design provided more information and increased retention of the route as well [P_{FS2}] and provided a "[P_{FS5}] more interactive, almost dramatic" experience. P_{FS4} believed that it was important to provide some sort of training[5.b.] or "legend for the landscape information(PoIs)" as in their current form "their meanings [were not] intuitively obvious"[5.d.] in any of the designs.

Design1 used earcons, based on piano notes, to provide turn instructions[6.b.]. Most of the participants originally considered them to be distracting and obtrusive[6.a.]. Participants P_{FS1} , P_{FS2} , P_{FS6} and P_{FS8} said that they were noisy and too loud[6.d.] and "[P_{FS3}] really messed with the voice". P_{FS3} also said that it was too stressful to count the number of beeps and distracted from the other instructions as well. After having the design explained (Q2 in Appendix C), some of the participants changed their minds regarding their usefulness[6.e.]. For instance, P_{FS2} initially stated that the "beeps didn't mean anything" but later stated that if they were quieter and "spaced proportionally to the distance between the streets [they] would pay attention to them".

Customisation. The importance of having the ability to customise was clear throughout the analysis. The participants discussed choosing between content[8.a.], setting speed[8.b.] and volume[8.c.] of the playback as well as setting speed and volume of the individual stems. P_{FS5} suggested including a "couple different modes based on preference" so that the "user can then combine any of the three forms of feedback they wish to hear". P_{FS1} preferred having an overview with only the functional information if they wanted a quick overview, and

adding AIs when they wanted more information about the surroundings. P_{FS1} wanted to reduce the volume of the earcons in comparison to the speech while P_{FS4} wanted to reduce the speed of the speech.

Training. P_{FS1} , P_{FS2} and P_{FS4} mentioned that they did not understand the meanings of most of the AIs and a legend might help gain familiarity. Similarly, for the earcons, none of the participants, except P_{FS5} , understood their design till it was explained in the survey. This may have led to a general dislike or bias against the use of these audio cues. Conversely, training may increase familiarity and hence usability of the system[9.a].

4.5 Discussion of the findings of the Design Study

Through this study, several design implications were drawn which informed the design of auditory route overviews. The expert participants gave guidelines for good auditory display designs.

The designers discussed the use of synthetic speech, AIs and earcons for representing different features of the map. Panning technique was a popular choice for representing turns or placing objects on either side of the route. Finally, adding a drone sound in the background to link the different route objects and indicate that the auditory display is still running. The users considered functional route information most useful, while PoIs were considered helpful but secondary. Speech was their medium of choice. A reason for this could be that since all the participants were proficient speech-based screen-reader technology users, it is possible that they had an innate bias towards a speech-based display.

An important quality of the auditory overview was to provide a quick feel of the route. This meant that the display should be short, informative and clear. The designers used abstract signifiers, like AIs and earcons, to achieve this. For example, instead of saying "there is a park to the left", they used an AI representing a park panned to the left. Then, while connecting them together in the route, they phased the sounds out to prevent dissonance and produce harmonious auditory displays. The users considered these AIs and earcons useful for validating the speech or adding an extra level of detail, but not to provide any functional information, like distance. Moreover, they also felt that training was required to learn their design, and also to familiarise themselves with the system.

Adding customisation capabilities was considered important by both groups of participants. It would increase the usability of the system by allowing the users to choose the content they need, as well as set variables like speed and volume according to their preference.

The following section describes these decisions, the rationale behind them and their implementation to develop the first prototype of the system.

5 DESIGN DECISIONS AND IMPLEMENTATION

The outcomes of the Design Study (Section 4) led to the formulation of design requirements for a system that produces an auditory route overview. In addition, literature recommendations were also considered as well [Guerreiro et al. 2017; Hennig et al. 2017; Kitchin and Jacobson 1997; Yatani et al. 2012]. This included the use and design requirements of speech, AIs, earcons and drone as well as ways of integrating them together to create an auditory display (Figure 8). Cycles of prototyping and testing with other designers as well as non-designers led to further refinement of these specifications for the design of the first prototype of the auditory route overviews detailed in this section. Software was developed to generate the overviews automatically according to this design.

Broadly speaking, these finalised specifications imply that the auditory display for route overviews should be automatically generated upon entering the origin and destination coordinates. A list of sounds should be created for audible PoIs, the audio should be sequential and should be an integration of AIs, earcons, synthetic speech and a drone as shown in Figure 8. The details of these are given below, followed by their implementation in the development of a prototype system.

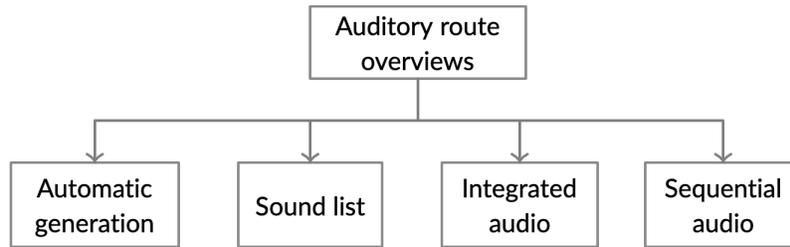


Fig. 8. Design requirements for auditory route overviews

5.1 Integrated audio

According to the blind participants of the Design Study, PoI information alone was not very useful for guiding travel and must be augmented with more concrete direction information. Similarly, using speech alone would make the system less engaging. Thus, a design in which different components were integrated was selected for effectively representing the route information. The integrated audio included AIs, earcons, speech and a background drone as given in Figure 9.

The number of sound elements on any single section of the route, that is, between the turns, was limited, according to [Hennig et al. 2017; Nielsen 1994], which states that humans cannot remember multiple instances of abstract information provided to them in rapid succession. Hence, the overview was designed such as not to overload the users, while providing maximum useful information in a short duration. Some of the design parameters of the auditory route overviews were: short duration, easy to understand and easy to recognise and recall.

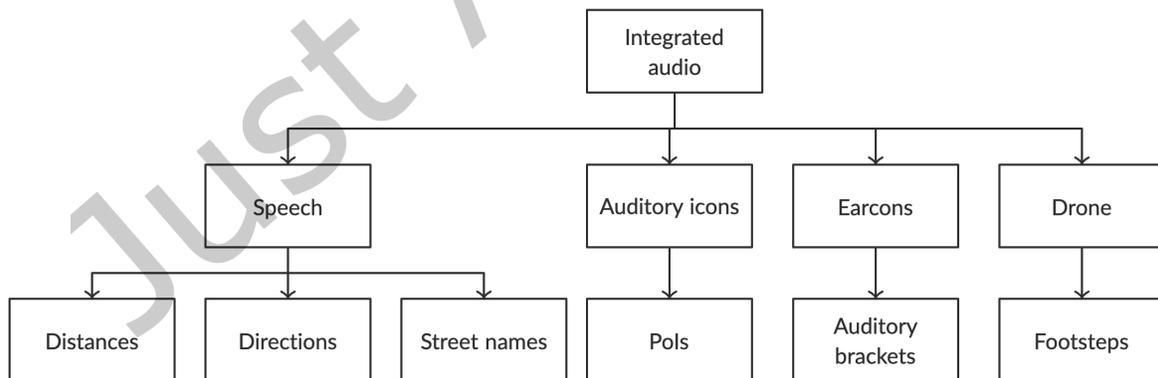


Fig. 9. Components of the integrated audio

5.2 AIs can represent PIs

Pis include permanent features like parks or train stations as well as temporary ones like traffic. The second design decision was to represent these with AIs. The design of AIs was again an iterative process, consisting of several cycles of design, testing and modification, discussed later in Section 5.6. Some of the design parameters chosen for AIs were: representative sound, brief, immediately and universally recognisable.

During the Design Study, some blind participants showed concern that all of the sounds might not be present during the actual journey, causing confusion. For example, if the user expected to hear chirping birds depicting a park, but does not hear those sounds due to any reason, such as time of the day, weather, etc. during the journey, they might lose their orientation and feel lost. This relates to the objective of this system, that the auditory route overviews are for planning journeys during pre-navigation. Similarly, the AIs are symbols representing an instance of the PI on the route. The purpose of the PIs is not to imitate the actual sounds that would be found on the route or guarantee that they would be heard when the user makes the journey. Instead, it is to provide a sound marker that is strongly reminiscent of the feature being represented and there is no guarantee that the chosen sound marker would be heard while making the specific journey, for example children may not be in the playground of a school, cafes might be closed or no trains running in the vicinity. Thus, they may or may not hear the same sounds during their actual journeys.

5.3 Speech should represent distance, directions and location

Representing distance information was one of the major challenges faced by the expert participants of the Design Study. Some of them proposed to use time delay to depict distance between two instances on the route, such as changing directions or between PIs, etc. However, none of them was able to effectively include sound representative of distances in their AD. Some of the participants suggested that earcons may be a good choice. Using earcons can make the distance information more tangible and easy to follow, as mentioned by P_2 . However, adding earcons would require a certain level of training and concentration, increasing cognitive load. A more intuitive way of representing distance was speech. It was the preferred method of the blind participants of the Design Study, where the majority insisted that important functional information, such as directions and distances, should be rendered in speech. Therefore, the third design decision was to use speech to represent distances, directions and street names.

To design the speech, some of the design parameters chosen were: the amount of information, clarity and speed.

5.4 Earcons should represent length of PIs

The fourth design decision came from the testing of the prototype sounds. It was observed that some PIs, henceforth termed repeating PIs, stretched over some significant geographical area, such as a school, university or park. Similarly, there were some that recurred consecutively on the route, such as shops on a high street. It was found that they were difficult to represent. Representing them literally would mean a repetition of the same AI for the length of the geographical area. This was both distracting and annoying, and added very little to the understanding of the route. One way of handling this could be to add fast-moving footsteps sound to represent an unchanging scene briskly, however, the repeated AI would still be unpleasant. Another way could be to represent the start and end points of the repeating PI and suppress the remaining instances. This is based on the ideas of grouping related objects together to aid quick learning and minimise memory load [Petrie et al. 1997] as well as hiding complex objects to allow greater control over information flow and facilitate disambiguation of grouping [Stevens 1996]. Thus, the next design decision was to adopt this idea and represent it using earcons, called auditory brackets. This method also provided more flexibility for designing routes with several repeating PIs, or PIs that nested between repeating PIs.

The auditory brackets were designed as a pair of earcons, one for the opening bracket, and the other for the matching closing bracket. At the first encounter of a repeating PoI, an opening bracket was included to precede the AI for that PoI. Similarly, at the final detection, the same AI was played following the closing bracket, representing that the PoI was present continuously between the brackets, as shown in Figure 10(b). The remaining repeated occurrences were muted. Hence, for example, instead of showing up as "shop, shop, shop, shop, shop, shop", it was now represented as "opening bracket, shop, ..., shop, closing bracket". Furthermore, other PoIs may appear within these brackets, as individuals or as other brackets nested in between. If there was only two instances of the AI to be represented within the brackets, two quickened footsteps sounds were played to represent that.

The design parameters for the brackets were to be metaphoric, short, easily recognisable, easily understandable and sufficiently distinct from the AIs.

5.5 Drone should represent travelling along a route

The display required a way to indicate a pedestrian progressing along the route. In order to achieve this, footsteps sounds were used as a drone. This served a dual purpose. Firstly, they were a natural representation of passing through a route. Secondly, they could be modified according to the type of terrain of the route, for example walking on a road, or gravel and so on. This could potentially improve the route knowledge of the user in terms of the different terrains and their requirements on the route [Macdonald and Stockman 2018]. The design objectives for the drone were: consistency, distinctness and a clear indicator of progress on the route.

5.6 Implementation

The design decisions derived from the Design Study informed the first prototype of the auditory route overview system. The system automatically converts route and PoI information from a map to its corresponding audio. Each element in the auditory route overview was designed according to the design decisions drawn from the previous studies. This prototype was tested afterwards in the Usability Study (Section 6) to determine the effectiveness of these design decisions.

A software system was developed to automatically generate the auditory route overviews. The software consisted of two parts, as shown in Figure 10. In the first part, map information was extracted from the Open Street Maps (OSM) and GraphHopper² APIs. The route map data, including street names and PoIs were taken from OSM, while the pedestrian routing information, including turns and distances were taken from GraphHopper. All of these were then transmitted to the second part of the software, the Map to Audio Generator (MAG).

5.6.1 Map information and audio generator. To generate the auditory route overviews, route map data taken from OSM and pedestrian routing information taken from GraphHopper was imported into Python. Map data was taken in smaller windows of 5 m x 60 m (5 meters forward and 30 meters on both sides) sliding over the route that was input from GraphHopper, as shown in Figure 11 [Yatani et al. 2012]. This allowed to access from OSM all the PoIs that were present only in the 30m distance of each side of the route in 5 m steps. A list of PoIs that were of interest, comprising approximately 40 elements, was created. This included shops, railway stations, playgrounds, parks, schools, places of worship, hospitals, cinemas, fire stations, police stations, etc. All instances of these PoIs were then stored in an array to be included in the auditory route overview.

Data was extracted from each sliding window and automatically converted into its corresponding audio. The data included turn directions, street names and distances between turns from the GraphHopper router and PoIs from OSM.

5.6.2 AIs. Some of the PoIs were relatively straightforward to represent as audio, such as reverberating claps for theatre or gavel sound for court. Some of these sounds were immediately recognisable, as seen from the

²www.graphhopper.com

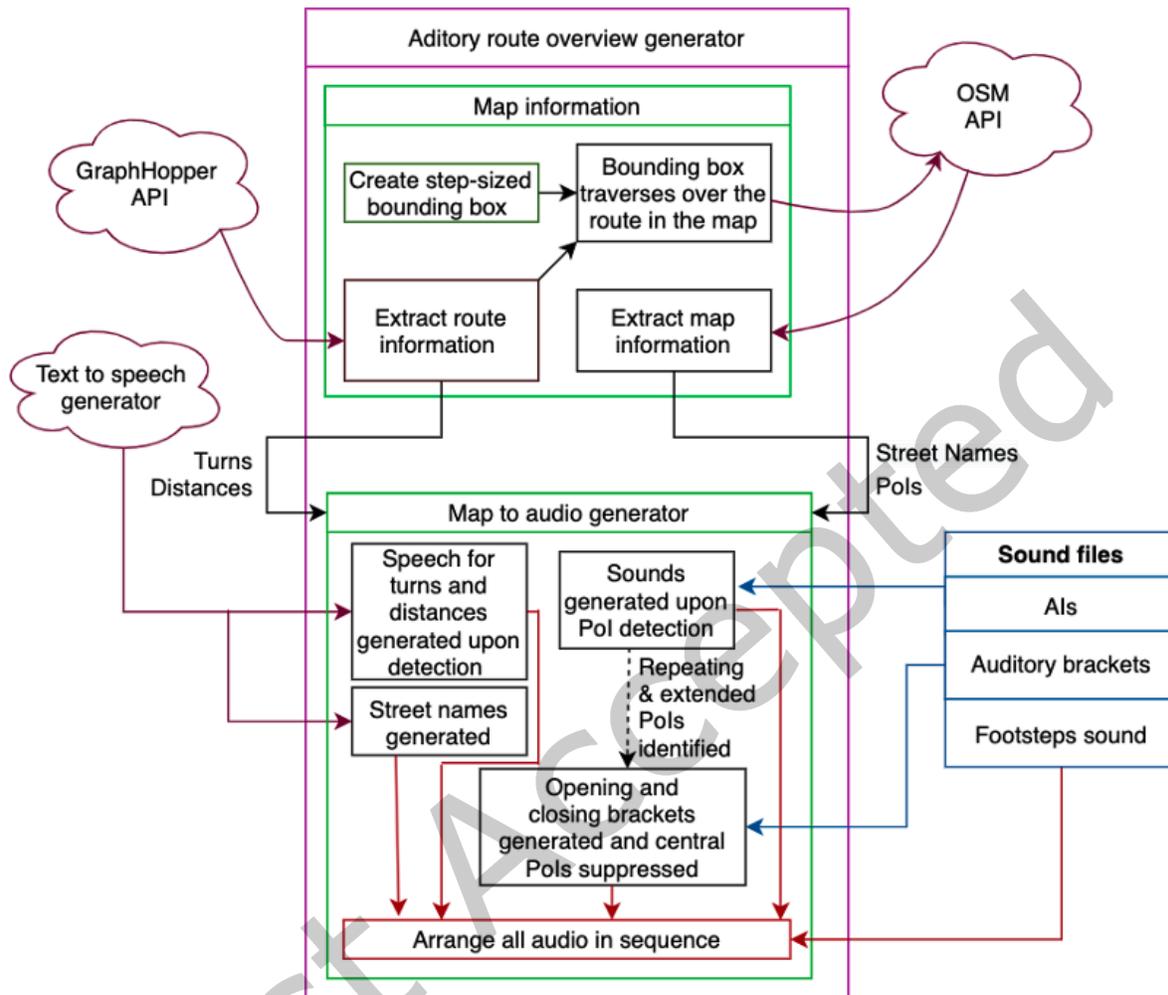


Fig. 10. Software architecture diagram for auditory route overview generator system

Usability Study Section 6, and could convey their meaning in a short time span of a couple of seconds. Some others, however, were much harder, as they did not have an obvious sound associated with them, such as a library or university, or could have several sounds to choose from, such as place of worship. For these PoIs, sounds representing their themes were used. For the library, the sound of a flipping page was chosen. While the sound isn't audible when passing by a library, it is immediately recognisable, universal and brief. For places of worship, church bells were considered appropriate for representation as they are brief, universal and easily recognisable as a place of worship. Considering this is an overview, a generic AI was used to represent all shops, rather than having individualised AIs for different types of shops.

Once an initial sound list was developed, it was crucial to determine whether the chosen sounds were suitable. That is, they were effectively representing the PoI, concise and not bothersome. All sounds were subjected to

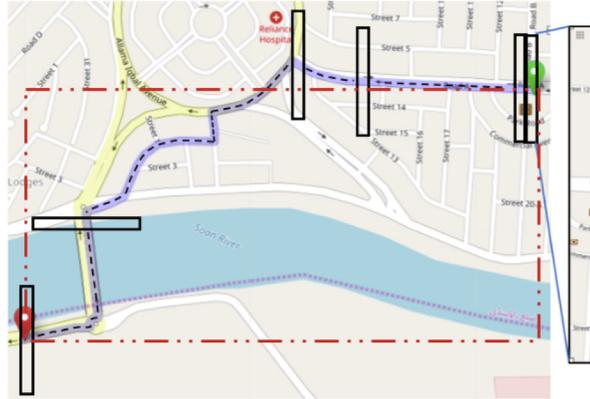


Fig. 11. Sliding window analogy for moving bounding boxes over the route. Including a zoomed-in version of the first bounding box on the route.

several rounds of testing with a variety of audiences to determine their intuitiveness, pleasantness and duration, as discussed in [Kortum 2008, Chapter 5]. These included a range of participants, including expert audio designers to individuals with no background in sound. The expert designers who audited the individual sounds at the prototyping stage are different from the expert designers who audited the individual sounds at the Design Study to obtain a naive perspective focusing only on the sounds. AIs were presented both individually as well as in context within the overall auditory display. In some instances, a number of candidate icons were presented and discussed in relation to a specific audio feature. The testing was done in this manner to expedite the design process and put more focus on the target user testing done later.

5.6.3 Auditory brackets. Auditory brackets represent the starting and end points of repeated PoIs. An example of a river is shown in Figure 12(a). If sonified as it is, the river AI will be played repeatedly each time the sliding window encounters it. To address this, the repeated PoI was replaced by auditory brackets (Figure 12(b)).

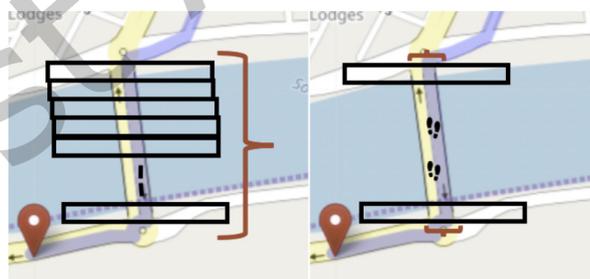


Fig. 12. Auditory brackets: (a) Left: Repeating PoIs (river) over several sliding windows, (b) Right: Replacing the sliding windows with an opening and a closing auditory bracket

The auditory brackets were implemented using a pair of matching earcons, implemented using rising and falling pitches. The rising pitch represents an opening bracket, the falling pitch a closing bracket. The tones were designed to last less than a second each and such that their sound was distinctively different from any of the AIs employed in the system

5.6.4 Speech. The speech utterances were designed to provide the exact information, without being too long. The overview started with providing the overall distance, duration and initial orientation of the user as speech. The overall distance was provided using both metric and walking time measurements, as suggested by Hennig et al. The subsequent distances between turns were given only by metric measurements. Similarly, the initial directions given were cardinal, followed by body-orientation indications, i.e. left and right [Hennig et al. 2017]. A typical speech instruction included the turn direction, the name of the street and distance to be travelled on it. For example, "Turn left on Gaby Street and move forward for 100 meters". The speed of the speech was designed to be comparable to screen-readers at 250 words per min, hence, it was reasonably fast and clear.

5.6.5 Drone. Footstep sounds were added concurrently with the entire auditory route overview track at fixed intervals [Macdonald and Stockman 2018]. The sound was very brief, around 1 ms and was consistently present over the whole track, to represent progress.

After developing the first prototype, a Usability Study was designed and conducted. The details of this study are presented in the next section.

6 USABILITY STUDY

The prototype auditory route overview system (Section 5) developed based on the design implications drawn from the Design Study in Section 4 was then tested in the Usability Study to investigate **RQ₃**.

6.1 Objective and Research questions

The objective of the Usability Study was to investigate how effectively the auditory route overviews, designed on the specifications drawn, communicated the route information. This information included distances, directions, PoIs and auditory brackets. Moreover, it also inquires if this information is useful and helpful to the users. This was done by user-testing of the developed prototype. The study was designed around the following research questions:

The study investigated how well the auditory route overview represented the route. It also investigated the effectiveness of the designed AIs in representing the designated PoIs and the designed auditory brackets effectively in representing the repeated PoIs. Finally, the Usability Study also explored the usefulness of the prototype (**RQ₁**).

6.2 Participants

Both blind (denoted as P_{US-B}) and sighted users (denoted as P_{US-S}) participated in this study. Testing with both populations had several advantages. It gave a chance to test the design decisions with a wider range of participants. It also allowed evaluation of broad usability features relevant to all users of the system. Moreover, it provided an opportunity to explore the use and understanding of the system by both user groups in detail.

Twenty two sighted and six blind individuals participated in the study. While it may seem like a small number, this is an acceptable sample size for participants with impairments ([Cairns and Cox 2008], ch. 16). The blind participants were recruited via snowball sampling amongst the contacts of the second author having several years of experience working with people with visual impairments. All of them were totally blind. The participants were aged between 24 to 58 ($M=47.67$, $SD=13.75$) years. All participants were comfortable with independent travel, either using a white cane or a guide dog. They all had at least 5 years experience with computers. Two participants rated themselves naive in terms of experience with auditory displays, three were intermediate with one as expert. Table 6 shows demographic information of the participants.

Sighted participants were recruited via an open call for participation. The ages for the sighted group ranged from 24 to 44 ($M=29.6$, $SD=4.6$) years. Eleven of them were female while the rest were male. All except one participant, P_{US-S16} , considered themselves naive auditory display users. P_{US-S16} rated themselves as intermediate. Details of their demographic information have been included as a table in Appendix D.

The study was recorded using video and still images, and investigated in several different ways.

6.3 Study design

For the evaluation of the designed auditory route overview system, a laboratory study was chosen over walking the actual route. The main rationale behind this decision was the safety of participants [Yatani et al. 2012], the objective of the study as well as this being the first prototype testing. While it may have compromised on the measure of effect it had on real journeys, it allowed to investigate each component of the design individually, as well as other measures like learnability, recall and ease of use, in a safe and stress-free environment, focusing only on the auditory route overviews. It also allowed testing for a larger variety of routes containing different types of PoIs that would be hard to find in actual pedestrian routes within a reasonable geographical distance of the University.

6.3.1 Task: The study comprises two tasks: 1) reconstruction and 2) recognition [Guerreiro et al. 2017; Kitchin and Jacobson 1997]. For task 1, participants had to listen to auditory route overviews and reconstruct them using Lego blocks. This included length and placement of Lego blocks representing street blocks, turns, and placement of PoIs and auditory brackets. For task 2, they had to recognise the PoIs and the auditory brackets placed in the first task. Each participant performed 3 trials with a different route each time. The participants could replay the audio route as many times as they wanted. The average time to complete the whole study was about an hour to ninety minutes per session. During reconstruction, the participants were requested to verbalise freely and their responses were recorded for analysis. A final questionnaire was administered to obtain a subjective evaluation of the experience.

6.3.2 Setup: The study was arranged in a silent room, where the participants were seated comfortably for the duration of the experiment. The auditory route overviews software was run on an Apple MacBook. The setup consisted of a set of Lego blocks and corresponding base plates. Participants were required to assemble the LEGO blocks on top of the base plate (Figure 13). Audio and video recordings were made to capture participants' actions and responses during the study for further analysis.

6.3.3 Lego: Lego was chosen as the apparatus for route reconstruction to provide a quantifiable tactile representation of the auditory route (as in [Guerreiro et al. 2017]) (Figure 13). Nine different LEGO lengths were provided in separate bins to represent the different distances between turns in the route. The blocks were labelled according to the lengths they represented: 2 studs for 10 meters, 3 for 50 meters, 4 for 100 meters, 6 for 150 meters, 8 for 200 meters, 10 for 250 meters, 12 for 300 meters and 16 for 400 meters. Participants were informed that they could compose the route by using a single LEGO block for each street [Guerreiro et al. 2017; Yatani et al.

Table 6. Demographics of the blind users for the Usability Study

ID	Gender	Age	Sight category	Onset of sight loss	Experience with assistive tech
<i>PUS-B1</i>	M	38 years	Totally blind	25 years	15 years
<i>PUS-B2</i>	F	57 years	Totally blind	17 years	30 years
<i>PUS-B3</i>	M	24 years	Totally blind	8 years	15 years
<i>PUS-B4</i>	F	53 years	Totally blind	16 years	25 years
<i>PUS-B5</i>	M	56 years	Totally blind	12 years	-
<i>PUS-B6</i>	M	58 years	Totally blind	1.5 years	30 years

2012]. Turns were represented by right-angled (L-shaped) Lego bricks to show left or right directions. PoIs were given by 1x1 Lego blocks and auditory brackets by 2x2. To ensure that the effort required to use the experimental setup was uniform for both sighted and blind participants, the bins were also labelled with special audible labels which were read using a label reader called PenFriend®. The rest of the experimental setup was identical for both groups.

6.3.4 Routes: Six routes were created to generate auditory route overviews (attached in Appendix E). Each route had similar complexity, containing eleven AIs, four pairs of auditory brackets, five legs and four turns. All turns were right angled. The first direction in the route was a cardinal direction (N, S, E or W), specified by the compass marker on top of the base plate (Figure 13). This information was provided to the blind participants verbally, stating that North was in front of them. All subsequent directions were left or right.

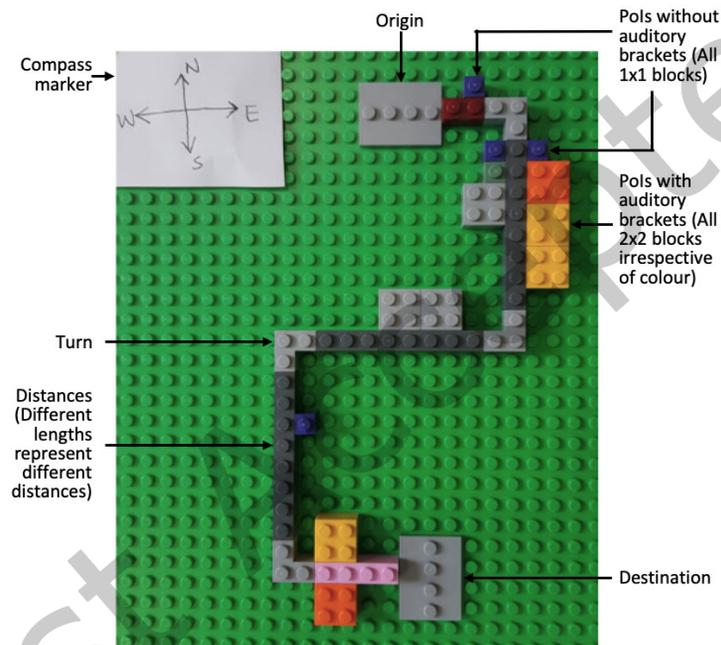


Fig. 13. Demo auditory route reconstructed using Lego blocks to aid training

6.3.5 AIs: Sixteen PoIs were chosen and their AIs were designed to be included in the study. They were chosen randomly within a route, akin to real routes, while the overall number of PoIs in a route was fixed at seven. The PoIs included churches, parks, playgrounds, restaurants, hospitals, shops, road crossings, sports centres, canals, police stations, fire stations, bus stations, schools, universities, libraries, theatres and cinemas. The AIs were designed on the same principles as discussed earlier, in the *Implementation* section.

6.4 Procedure

6.4.1 Training: The study involved a short 10 - 15 minute training period, where the participants were introduced to the concept of auditory route overviews, the AIs, and the experimental apparatus. A demo auditory route overview was played, accompanied by a reconstructed Lego route of the same journey, as shown in Figure 13.

The concept of auditory brackets was explained with examples. Opening and closing auditory brackets as well as all the AIs were presented for training at their own pace. They were free to repeat the sounds till they were comfortable with them. The blind participants were given additional time to get acquainted with the label reader and the overall setup.

6.4.2 Experiment data: The experiment consisted of two tasks: reconstruction and recognition.

Firstly, the form of the route was recorded and compared to the original route. This included the number of street blocks (represented by straight lines), length of street blocks (representing distances) and turn directions. Secondly, the number and placement of the PoIs were extracted and compared. Finally, the same was repeated for auditory brackets as well. Furthermore, the time taken by each participant during training (training time) and then later reconstructing the routes in each trial was recorded [Yatani et al. 2012]. The number of times they replayed the route overviews (route replay) prior to reconstruction was also recorded. Some examples of participants' route reconstruction tasks are given in Figure 14).



Fig. 14. Routes reconstructed by participants using Lego blocks for different trials

For the recognition task, the participants were asked to listen to the overview after reconstruction and verbalise the recognised PoIs and auditory brackets as they heard them. The responses were audio recorded as well as noted in tables by the author. These were then investigated for recognition as well as order.

6.4.3 Exit survey data: At the end of the Usability Study, the participants filled out an exit survey, consisting of both Likert-type and open-ended questions. This helped obtain a subjective evaluation of their experience as well as further ideas for improvement from the participants. For blind individuals, the questions were asked verbally, and the responses were recorded as audio, later transcribed manually for further analysis. The Likert-type questions included:

- **Usefulness:** Rate the level of usefulness for you of the auditory routes.
- **Confidently recognising AIs:** Rate your level of confidence while understanding the auditory elements along the routes (AIs).
- **Easily recognising AIs:** Kindly comment on how easy or difficult it was to recognise the AIs.

6.5 Results

6.5.1 Data analysis metrics: To evaluate the reconstruction and recognition tasks and the participants' mental representation of the route, metrics from studies [Guerreiro et al. 2017; Passini et al. 1990; Yatani et al. 2012] were adapted accordingly for the data captured:

- **RouteRecError:** The error in recreating the route. It consists of the following two errors relating to the shape or form of the route and the number of street blocks in it.
- **FormElementsError:** The Levenshtein distance [Guerreiro et al. 2017; Passini et al. 1990] between the correct route and the participant's route reconstruction. This corresponds to the minimum number of operations (deletions, insertions and substitutions) to correct the participant's route and targets the form of the route, including the length of each block but excluding the placement of PoIs and auditory brackets.
- **NumberElementsError:** The number of missing or unnecessary street blocks used to recreate the route.
- **PoIsOrderingError:** The Damerau-Levenshtein distance
- **PoIsPlacementError:** The number of PoIs that are not in the correct street block. [Guerreiro et al. 2017] between the correct PoI order and the users' ordering. It corresponds to the minimum number of operations (deletions, insertions, substitutions, transpositions between adjacent PoIs) required to correct the participant's ordering.
- **PoIRecogError:** The number of PoIs that are incorrectly recognised in the route.
- **ABsRecogError:** Comprised of AB_LRecogError (left hand side bracket) and AB_RRecogError (right hand side bracket). The number of auditory brackets that are incorrectly recognised in the route.
- **ABsOrderingError:** Comprised of AB_LOrderingError (left hand side bracket) and AB_ROrderingError(right hand side bracket). The Damerau-Levenshtein distance [Guerreiro et al. 2017] between the correct auditory brackets order and the users' ordering or are not in the correct street block or are missing.

Training time, reconstruction time and route replay were analysed over trials to investigate their effect on the outcomes and learning over time. This is shown in Figure 17. Figure 15 presents the results of all the route, PoI and auditory brackets error metrics for both sighted and blind participants.

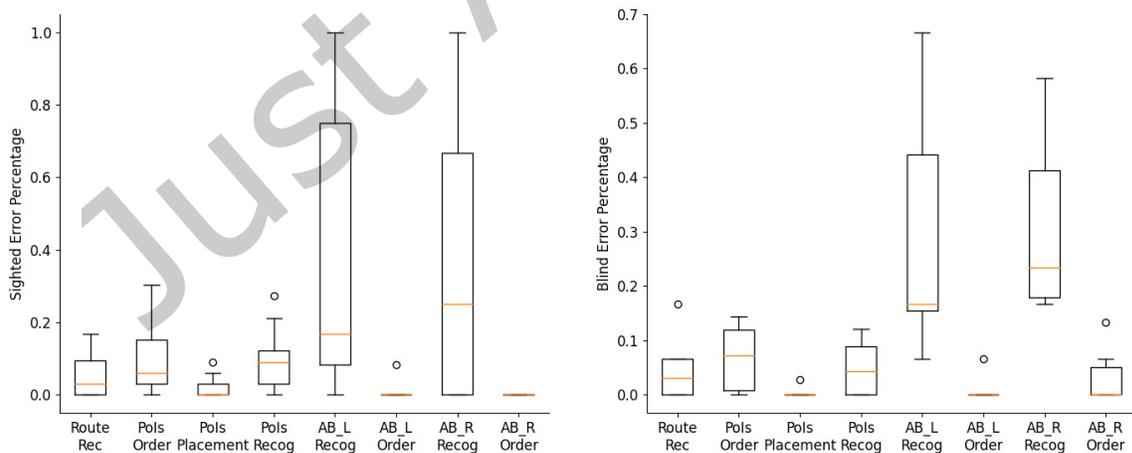


Fig. 15. Performance in route reconstruction and recognition. BoxPlots show median, IQR, min, max and outliers.

6.5.2 Route accuracy: 6 sighted and 3 blind participants accurately reproduced the route form, including the lengths of the street blocks. Most of the errors in route reconstruction were FormElementsErrors, which included 7% incorrect length of blocks for sighted participants and 4% for the blind and 3% incorrect direction of blocks for the sighted and 1% for the blind. From all the participants in both groups, only 2 sighted participants had unnecessary or missing street blocks. Thus, even though they were able to understand and recall the sequential steps of the route, both groups of participants had slightly more difficulty with recalling the correct lengths of street blocks, followed by directions, as shown by participants' RouteRecreateError in Figure 15.

6.5.3 Pol accuracy: The sighted participants placed, on average, 10.14 (~91%) PoIs into their Lego routes while blind participants placed 10.22 (~93.2%). Six sighted and two blind participants put all eleven PoIs in their reconstructed routes. Out of these, all but one PoIs were placed in the correct order by the blind participants. Five sighted participants placed 9 PoIs in the incorrect order altogether. Thus, almost 90.5% PoIs were placed correctly by sighted participants and 96.36% by blind participants.

For the recognition task, an average of 10.03 (~91%) PoIs were correctly recognised and recalled by the sighted participants while 10.72 (~95%) by the blind participants. Figure 16 is a confusion matrix showing the details of the recognised PoIs by the participants against the actual PoIs. The different shades of red represent a higher percentage of matches, with pure red being a perfect match while bluer shades representing lower matches going down to 0 (shown in the colourbar in the figure). These give a better insight into which AIs were easily recognised and recalled by both groups of participants, and which ones could be improved further.

The figure shows that all blind participants were able to recognise all instances of parks, sports centres, libraries, theatres, fire stations and cinemas, while recognising the AIs for road crossing, playground, university and police station was more erroneous. 8 instances of road crossing, in all, were presented to the participants during the study. Out of these, 2 were misrecognised as bus stops. Out of 9 instances of playground, 1 was misrecognised as a restaurant and 1 other as a school. Out of 4 instances of university, 1 was misrecognised as school. Similarly, out of 3 instances of police station, 1 was misrecognised as a hospital.

For sighted participants, the AIs for playground, canal, library and cinema were recognised 100%. Conversely, fire station, police station, theatre, road crossing and school AIs had recognition rates less than 80%. The theatre AI appeared 17 times in the study. Out of these, it was correctly recognised 10 times, misrecognised once as a church. School AI was presented 41 times, 34 of which were correctly recognised, 1 was misrecognised as a road crossing and 1 as hospital. As the figure shows, the fire station and the police station AIs were the most misrecognised. There were 14 instances of the fire station AI, out of which only 2 were correctly recognised. 11 were misrecognised as police station and one as road crossing. Finally, out of 8 instances, the police station was correctly recognised 3 times and misrecognised as fire station 5 times.

6.5.4 Auditory brackets accuracy: On average, 2.5 out of 4 left auditory brackets and 2.6 out of 4 right auditory brackets were inserted into the Lego routes by the sighted participants. 2.77 and 2.72 out of 4 left and right auditory brackets were inserted into the Lego routes, on average, by the blind participants. All but one sighted and two blind participants recognised all auditory brackets correctly. Participants P_{US-s3} , P_{US-s5} and P_{US-s16} recognised and placed all auditory brackets without any error. However, the overall ABsRecogError was significantly larger than all other errors at 36% for sighted and 32% for blind participants, as shown in Figure 15.

6.5.5 Changes in reconstruction time and route replay over trials: The results in Figure 17 show a decrease in both reconstruction time and route replay over the three trials performed by each participant in both groups. The reconstruction time reduced by approx 4.6 minutes on average (36% decrease), falling from 12.6 minutes on average in the first trial to 8 minutes on average in the last one, for the sighted participants. For the blind, it reduced by approx 6.4 minutes on average (34% decrease), from 19.2 minutes to 12.8 minutes on average. The

number of replays reduced by 2.24, from 8.52 on average to 6.29, a decrease of approx 24% for the sighted and 3, from 13 on average to 9.83, a decrease of approx 26% for the blind participants.

Shapiro-Wilkinson tests were applied to all dependent variables to check for normality. One-way ANOVA tests on sighted participants data for both route replay and reconstruction time ($F_{replays}(2,63)=3.70$, $P=0.03$ and $F_{time}(2,63)=10.1$, $P=0.0001$) showed that the changes in values over trials was statistically significant. Training time had no significant effect on learning.

6.6 Usability feedback on system design

The exit survey was analysed to obtain user feedback on system design.

6.6.1 Data analysis methods: The open-ended questions in the survey inquired in more depth about what the participants **liked** and **disliked** in the auditory route overviews, as well as their opinion regarding the **level of detail** provided in the overviews. The open-ended questions were analysed thematically, as before in Section 4.3.4 and Section 4.4.5, using an iterative, inductive approach to identify themes and sub-themes [Braun and Clarke 2006].

6.6.2 Findings: The rating questions feedback, given in Figure 18, showed that nine sighted participants thought that the auditory route overviews were hard to understand. Another nine thought that it was moderately difficult, while the final three considered it to be easy. None of the sighted participants considered it too hard or too easy to understand. For blind participants, one considered it hard to understand, two voted moderate difficulty, another two thought it was easy and the final one thought it was very easy. None of the participants thought it was very hard.

Four sighted participants considered the auditory route overviews very useful, twelve considered them useful, another four thought they was neither useful nor useless and one thought they were useless. For blind, three out of six considered them to be very useful, two considered them to be useful and one thought that they were neither useful nor useless.

Finally, two sighted and one blind participant felt very confident in recognising AIs, eleven sighted and three blind felt confident, another two sighted and one blind were neither confident nor confused, while six sighted and none of the blind participants was confused. None of the participants felt very confused.

Table 7. Comparison of responses by sighted and blind participants

Attributes	Sighted	blind
Positive attributes of the design	Pleasant and informative	Gives PoI relative to road
Negative attributes of the design	Speed	Auditory brackets
Features for customisation	- Speed - Amount of content	- Speed - Amount of content - Type of content - Direction information
Missing information		- Spatialisation - Pedestrian crossings - Side roads
Modifications	Reduce the PoIs	Add clock-face turn
Evidence of learning		Felt less confused over time

Thematic analysis of the open ended survey questions revealed that both groups of participants found the design to be both usable and useful. P_{US-B1} stated that they found having the location of landmarks especially useful. They suggested changing turn-directions to "o-clocks" to give "twelve reference points". P_{US-B4} suggested adding spatialisation to improve the mental image of the route. Both groups almost unanimously stated that they wanted to be able to customise the auditory display according to their preference.

Eleven sighted and four blind participants considered the amount of detail provided appropriate for an overview, while two sighted and two blind participants wanted adding more information to make the auditory route overviews more useful. For instance, participant P_{US-B2} suggested to include side roads that are not a part of the route to the overview and P_{US-B2} and P_{US-B4} suggested to add pedestrian crossings. Conversely, three sighted participants wanted to decrease the number of AIs. P_{US-S15} questioned whether some of them "add[ed] information" useful for navigation. However, none of the blind participants suggested reducing the information.

Participants P_{US-B4} suggested designing the route in layers, having different information in each layer and the ability to "pick levels of the route".

Discussing the study design, participant P_{US-B6} felt "very confused" at the start, however, got more comfortable over the trials. P_{US-B2} felt that the tactile nature of Lego "really help[ed] consolidate a route in [their] mind". P_{US-B5} also liked the tactile way the routes were reconstructed.

A summary of the themes are shown in Table 7 comparing the responses between the two groups of participants.

6.7 Discussion

The results from the route reconstruction tasks and feedback survey were examined in light of the research questions.

Effectiveness of the auditory route overview design in representing the route: The results showed that the auditory route overview design was representative of the route. Participants of both groups were able to reconstruct the form of the route fairly accurately, while having some difficulty recalling the lengths of street blocks. This finding is similar to [Guerreiro et al. 2017], however, arguably less critical here, since this is an apriori system designed to provide route knowledge to enable strategic decision-making regarding the journey. Some blind participants wanted more details in their overviews. This is in line with the findings from [Hennig et al. 2017], where 50% of their blind participants stated that they would like to have more detail in the information provided to them. Whilst this is an overview, provisions to customise the amount of information presented can be made in future.

Effectiveness of the designed AIs in representing their designated PoIs: The design of AIs for representing PoIs was tested using mixed methods. The reconstruction and recognition results showed that the participants in both groups ordered, placed and recognised the majority of the PoIs fairly accurately. Placement and recognition errors were higher for both groups, but still less than 10 percent. Feedback also showed that participants were mostly confident in recognising the PoIs from their AIs. P_{US-S5} thought that the designed sounds were good and "represent[ed] what they mean[t]". However, some AIs were less easily recognisable. For most of the participants, it was hard to differentiate between the fire station and the police station. This was perhaps because the original siren sounds of these two services were used as AIs. Although they have distinctive elements, on the whole the pattern is quite similar, thus may have caused confusion. Similarly, the bus stop and road crossing AIs also caused confusion, particularly for the blind participants. Both P_{US-B1} and P_{US-B2} commented that "the road [crossing] and the bus [stop] were difficult to tell apart". Even though the AIs for these PoIs were not similar (refer to sounds attached as supplementary material in Appendix E), their implied contexts are the same. The road crossing sound was designed using engine sounds, which might be perceived as similar to a bus engine sound causing confusion between the AIs. Similarly, playground and park sounds were also considered difficult to tell apart. As P_{US-S4} mentioned that "I confused some of the pairs quite easily ...[for example] park versus playground ... although not

because of the sounds [but] because I was blending these pairs together when I thought about the route". P_{US-B1} felt that while some of the AIs were similar "more training would make it more easier" to recognise them. Other participants also felt that their confidence in recognising the AIs increased over trials. Thus, designing AIs to be more distinctive in their sound patterns and increasing the training times can help further improve recognition.

Effectiveness of the designed auditory brackets in representing the repeated PoIs: The concept of auditory brackets to represent the length and proportion of a PoI in a route, as well as representing overlapping PoIs is a novel concept used in this work. It is drawn from the ideas of grouping together related instructions to increase learning speed and minimise cognitive load [Petrie et al. 1997] and hiding complex objects to increase control over information flow [Stevens 1996]. The participants appreciated the idea of having a sense of the size of the POIs relative to the route. P_{US-B2} stated that they liked knowing that, for instance, "this hospital is going to be a fair proportion of this pavement". Similarly, participants also liked the idea of presenting overlapping PoIs in a distinct manner. P_{US-S19} stated that they liked the idea of using auditory brackets to denote the start and end points of places and show that "a playground can be in the middle of a park". However, most of the participants from both groups struggled with placing the auditory brackets in the route. The auditory bracket errors in Figure 15 also shows much higher error percentages that those for route structure or PoIs. Several participants discussed how they struggled with the auditory bracket earcons. P_{US-P1} said that they "struggled the most trying to remember the opening and closing [brackets]". One reason for this could be the participants inability to distinguish the brackets from the AIs, either because of the speed of the display or because the AIs were masking the sound of the auditory brackets. This can be supported by the survey responses where nine out of twenty two sighted participants stated that they had a hard time following the opening and closing brackets, especially when they were nested. Another reason is that since this was a novel concept for the participants, they might have required more time in training to familiarise themselves better. Hence, while the idea of auditory brackets for representing repeated PoIs may be considered useful, the design of the earcons either needs to be modified or requires more training than the current study provided.

Usefulness of the auditory route overview system. Auditory route overviews had high perceived usefulness and acceptance from both groups of participants. The sighted participants, on average, considered it to be useful, while the blind participants considered it to be very useful for supporting their independent travel. The main advantage of this system for the users is the knowledge of the route gained, which in turn would increase the confidence of the users during the actual navigation. The participants perceived the system to be useful for building a spatial model of the route in their minds including the surrounding PoIs.

Learning: Participants' comments and the trends of the graphs in Figure 17 indicate that the participants learned the system design over trials. The graph shows reduced number of replays required to learn the route and the time required to reconstruct it. Moreover, participants reported an increased confidence in recognising and placing PoIs over trials. This indicates that participant performance can improve over time with usage.

The next section presents a discussion of the overall research questions of this work and its contributions.

7 DISCUSSION OF THE OVERALL RESEARCH QUESTIONS

This research comprised three major studies: the Preliminary Survey (Section 3), the Design Study (Section 4) and the Usability Study (Section 6). The survey helped form a broad understanding of the need for auditory route overviews and some of the basic requirements, including the duration and content of the overview. Findings from the survey helped form the framework of the Design Study, including the tasks to be performed by participants and the data to be collected. This two-part study, with expert designers providing design perspectives and blind users specifying system requirements, helped draw detailed design specifications for auditory route overviews, given in Section 5. A prototype developed on these specifications was then tested in the Usability Study. The designed

system presents an overview of the chosen route information, including the form of the route, the distances and turns, as well as any points of interest (PoIs) along the way. As a preview system, it is designed to provide route knowledge of the journey and support planning and strategic decision-making during pre-navigation. The findings from these studies will now be examined in the light of the research questions of the project (Section 1).

RQ₁ : Is providing auditory overview of routes prior to walking considered useful by the blind community?

Various researchers [Guerreiro et al. 2017; Hennig et al. 2017; Lahav et al. 2018; Yatani et al. 2012] have shown the importance of having non-visual overviews of routes before travelling for the blind population. Lahav et al. [Lahav et al. 2018] gave a good argument for having a priori knowledge of new spaces and used a virtual environment based exploration of the space to create a mental map based on the map model. Similarly, Guerreiro et al. [Guerreiro et al. 2017] showed the merit of having a priori route information of segments of routes to build a sequential mental map during live navigation. In this research, the value of having a priori auditory overviews of routes has been investigated iteratively throughout its life cycle. Several blind individuals, both during the recruitment processes and as participants in various studies have highlighted the need for a system that can provide routes preview. During recruitment in an informal conversation, one individual commented that "this idea sounds promising. I believe that if we can acquire a mental map before heading out, that walking a route is simplified". Moreover, the findings from the Preliminary Survey showed that the preference of route overviews was significantly higher than the rest of the applications. Similarly, the participants of the Usability Study considered them to be quite useful as well. All of the blind participants gave high ratings to the level of their perceived usefulness, with half considering them very useful. Thus, while some participants disliked some features of the overviews and suggested several modifications to the design, overall, the response from the different participants in all the studies has been very positive with regards to the usefulness of the auditory route overviews. These results provide further motivation to undertake this research and highlights the requirement for more work in this area.

RQ₂ : What sort of route components and auditory design techniques can be used in such a route overview system?

The route components and auditory design techniques were extensively investigated in the Designer Workshop and User Feedback sessions of the Design Study. The designers chose particular route features, such as the audible PoIs, distances, directions, road crossing and orientation information, to include in their overviews. Similarly, they employed various techniques, such as mapping, creating a sound list and choosing AIs and earcons, to represent these different route components. The blind participants examined these designs for usability, usefulness and aesthetics. Based on the suggestions of the designers and the feedback from the users, a set of design specifications was drawn and the first prototype developed. Usability and usefulness testing of this prototype, as well as discussions from the previous studies, showed that the participants valued the functional information most, and wanted it to be clear and direct. The PoIs on the route were represented as AIs, as suggested by the designers, to give a richer knowledge of the route. There were several advantages to doing this. AIs also provided a holistic picture of the route for making purposeful journeys, such as going to a school or a church. They are also useful for providing localisation on the route.

RQ₃ : Are the chosen designs effective in representing route information?

Results from the Usability Study showed that participants were able to understand and reconstruct the form of the route fairly accurately, while having some difficulty recalling the lengths of street blocks. Similarly, most of the AIs were also considered representative and easy to recognise and recall. However, there were some, like

the "fire station" and the "police station" in the Usability Study that were confusing, possibly because of both similar sounding AIs as well as similar connotations. The "bus" AI was not considered very representative. One way of making the sounds more usable could be to create a database of sounds and allow the users to choose the representative sounds for each PoI themselves, thus personalising the system.

Another concern shown by the blind participants was that the AI sounds might not be present during the actual journey on-site, causing more confusion than adding to the route knowledge. For example, listening to the auditory route overview, the user might expect to hear church bells to recognise that they are passing a church on the route. However, for any reason, such as time of the day, the sounds may not be present, resulting in the users losing their orientation and feeling lost. This concern relates to the main objective of this system. The auditory route overviews system is designed to provide route information for planning journeys before embarking on them. Moreover, the AIs are symbolic sounds representing instances of the PoIs on the route. Thus, the auditory route overview is a description of a route using different speech and non-speech sounds with the purpose to provide information about the route. Similarly, the purpose of the PoIs is not to imitate the actual sounds that would be heard on the route or guarantee that they would be present when the user makes the journey. Rather, it is to provide a sound marker that is strongly reminiscent of the PoI being represented. The concern raised by blind participants is of course valid and needs to be addressed in the training provided before they use the system. It needs to be made clear that sounds that they hear when using the system to preview a route are symbolic of POIs they will pass along the route, but due to the time of day or other circumstances they may not necessarily hear those sounds as they pass. Further, whenever the application is started, a reminder of this fact could be included in text that appears before users start interacting with the application.

While developing the first iteration of the prototype, a need for representing extended and repeating PoIs was observed. If transformed as it is, it seemed that they were adding too much noise to the display while not adding anything to the route knowledge. The concept of auditory brackets, based on [Petrie et al. 1997; Stevens 1996], was introduced to the design, where earcons were attached to the starting and ending points of the extended and repeating PoIs and their remaining instances were suppressed. The earcons were designed as changing pitches representing opening and closing brackets. The participants of the Usability Study found the auditory brackets design hard to understand and follow. The design of the brackets will be investigated again in the next iteration of the system.

Finally, personalisation through customisability options is an important feature of a user-centred design. Some customisability following suggestions from the Usability Study, including speed of speech and muting the different stems of audio, that is, speech, AIs or auditory brackets will be added to the next iteration of the system. Moreover, to make the design more universal, a database of AIs can be created to give the users the ability to choose their preferred sound for representing different PoIs.

RQ₄ : In what ways has the user-led design practices influenced the design of the system? Why was it chosen?

Throughout this research, a user-led design approach has been employed to determine design requirements. It was based on an iterative process involving cycles of requirement gathering, rapid prototyping and user-based evaluations, aiming to determine design guidelines generated by the participants and hence suited to the target user population [Hermann et al. 2011, Chapter 7]. This is inline with recommendations by expert assistive technology researchers, including [Metatla et al. 2015a,b; Sahib et al. 2013; Spinuzzi 2005; Weinberg and Stephen 2002] who emphasise the involvement of target users in the design of systems. Various instruments including questionnaires, interviews and workshops were used at different phases of the research to collect user data, as both audio-visual and notes-based, which was then analysed quantitatively and qualitatively to draw design specifications. The findings regarding duration and content from the Preliminary Survey were investigated again

in the Design Study, during both sessions, and further feedback was obtained in the Usability Study as well. Similarly, the suggestions regarding contents of the auditory display by the designers in the Designer Workshop were discussed with the blind users in the User Feedback. Usefulness of the system for the users was investigated at every step of the research, from the Preliminary Survey to the Usability Study. This has also provided a chance to monitor the ways and strategies the users adopt while interacting with the system. For example, a finding of the User Feedback session was that direction was the most important route information for them, which they preferred to have as speech, as it is more explicit and requires no learning. Alternatively, however, most of the designers believed that speech took more time and was less flexible in terms of the things that it could represent. Similarly, the designers prioritised well-designed ADs with more abstract representations, using AIs, earcons and/or panning, over functionality. The blind participants felt that PoI information alone, as given in Design2 (Sections 4.2) was useless for guiding travel and must be augmented with more concrete functional information, like distance and directions. They felt that Design3, where all the components were integrated, i.e. having all or a combination of AIs, earcons and speech was most effective. All of these suggestions informed the design decisions and led to good usability and usefulness results in the Usability Study. Moreover, this discrepancy is representative of the gap between expert designs and user requirements and shows why products which are designed without user participation are often not readily accepted by the concerned community [Sachdeva and Suomi 2013], particularly if they are differently-abled.

According to literature, a popular way of designing user-centred systems is through participatory design setups where both the designers and the users collaborate to understand and create the designs [Metatla et al. 2015a; Sahib et al. 2013]. This brings the perspective and expertise of the designers and the requirements of the users together in one design. However, the Design Study was arranged as a 2 part study, with the designers participating in the first part, creating some example designs and the prospective users participating in the second part, providing feedback on those designs. This setup was preferred over the participatory method because there were no existing examples of auditory route overviews beforehand to show the users what it would sound like or contain. It was felt important to do so to create a sense of how these were different from navigation and exploratory systems, discussed in Section 2. Looking back, it also worked well because the blind participants participated online. This not only gave access to a larger sample of the population but also provided the participants the ease to perform the study from the comfort of their own homes as well as take their time to review, repeat and understand the auditory route overviews to answer the questions. These provisions would not have been available in a participatory process. Thus, while a participatory process is a good way of designing for niche populations, the two-part process used in this research also worked well for this particular research problem.

7.1 Contributions to knowledge

The work describe here makes the following original contributions to this area of research:

- C1. Evidence from all the studies in this research, and particularly the Preliminary Survey, that blind people find auditory overviews of routes to be useful and important for supporting independent blind travel [RQ_1]. Moreover, a significant gap in accessible application design due to the lack of overviews of systems or repositories of information, such as email boxes, complex documents and websites was identified through surveys.
- C2. Zhao et al. [2008a] provides the only clear guideline in the literature about the ideal length of auditory overviews. However, while their guidelines were suitable for their application, based on evidence from this study, at least for this application having this type of content, their recommendation seems too short. The participants of both the Preliminary Survey and the Design Study suggested that the duration should be proportional to the amount of information being imparted.

- C3. A consolidated set of design requirements for auditory route overviews gained from the blind population over different stages of the prototype development including the Preliminary Survey and the Design Study.
- C4. Analysis of the Design and the Usability Study showed that when designing an auditory overview, functional or main information, like distances or street names, could be presented as speech as it is clear and unambiguous. The ambient or environmental information or patterns of information could be provided using AIs.
- C5. Analysis of the Usability Study showed that although the design of Auditory Brackets needs to be further investigated, they can be a useful method to present PoIs that are either repeated multiple times or take up a considerable portion of the route.
- C6. According to the exit survey in the Usability Study, the blind users considered auditory overviews of routes easier to understand and more useful on average than the sighted users.
- C7. A software architecture for acquiring route and map information and converting it into an auditory overview.

8 LIMITATIONS AND FUTURE WORK

The current auditory route overview system only provides a passive overview of routes, with a high-level spatial relationship between street locations and PoIs. Making the system interactive and customisable will increase user control of the information and hence their engagement as well. According to Walker in [Hermann et al. 2011], for most sonifications to be useful there needs to be at least some kind of interaction capability, even if it is just the ability to pause or replay a particular part of the sound. This is also in line with [Yamamoto et al. 2011], which states that the success of an assistive system depends on providing means to consider individual preferences. Making the system interactive will also allow users to obtain their desired information latency-free in response to their interaction activity [Kortum 2008, Chapter 5].

The Usability Study design also added limitations, as all route features were synthesised to enable a Lego-based laboratory study. However, this study was not intended to test the efficacy of the concept of auditory route overviews, but rather investigate the design choices made. A future study should investigate the effect of auditory route overviews on travel decisions.

The Usability Study also recorded data for two different groups, however, no statistical comparisons were made in their performance owing to large imbalance in the sample size. While it was useful to do this for evaluating design decisions, it gave an insight into how sighted people use an a priori audio-only based route information system, and future work should be done to investigate this further.

9 CONCLUSION

This paper described developing and testing design guidelines for an auditory route overview for pre-planning journeys by blind users. The auditory display was designed by considering techniques and suggestions from audio designers and getting feedback on these from potential blind users. The overview was sequential and automatically generated as integrated audio. It comprised AIs to represent the points of interest (PoIs), earcons for auditory brackets encapsulating repeating PoIs, and speech for directions. A prototype based on this design was developed and evaluated in a user-study carried out with both blind and sighted participants. The findings show that both groups performed well in route reconstruction and recognition tasks. It was further determined that the route information and AIs were effective and useful in providing the route information and helped form a mental model of the route, which improved over time, exhibiting learning. However, the design of auditory brackets needs further improvement and testing. At all stages of the system, from the preliminary survey to user testing, input was acquired from the end-user population and the design adapted accordingly. This ensured

design characteristics particular to their preference, thus, increasing the probability of producing an application that would actually be beneficial for them.

10 ACKNOWLEDGEMENTS

We thank our participants for their time, effort and invaluable feedback and ideas to make this work possible.

Appendices

A DEFINITIONS AND ACRONYMS:

A list of definitions of technical terms and acronyms used in this work is included.

PoIs: Points of interest. PoIs are the elements along the route that can serve as waypoints and increase awareness about the surroundings and so can aid the creation of a memorable sequential representation [Guerreiro et al. 2017].

Auditory display: Systems that use speech or non-speech sounds to convey information or augment the user's experience. Auditory route overviews are a type of auditory display.

AI: Auditory icons.

Stems: A discrete or grouped collection of audio sources mixed together to make an integrated audio output [Hollyn 2009].

Drone: A status-tracking background sound used to enhance the sense of space or of time passing [Macdonald and Stockman 2018].

Participants of the different studies:

P_{PS} : Participants of the Preliminary Survey.

P_{DS} : Participants of the Designer Workshop session.

P_{FS} : Participants of the User Feedback session.

P_{US_B} : Participants of the Usability Study who are blind.

P_{US_S} : Participants of the Usability Survey who are sighted.

B SURVEY QUESTIONS FOR THE PRELIMINARY SURVEY IN SECTION 3

- (1) Do you think overviews are useful and important?
- (2) Following is a list of 6 applications that might benefit from overviews. Kindly rate each of them (1-5) for usefulness (Note: we are not asking here anything about how easy or hard you think they may be to design, but simply whether you feel if they existed they would be useful).
 - (a) Route overview before travel.
 - (b) Overview of email box for new emails.
 - (c) Overview of a document.
 - (d) Overview of a spreadsheet.
 - (e) Overview of a single web page.
 - (f) Overview of a complete website.
- (3) It has been suggested in research literature that auditory overviews should last about 10 seconds.
 - (a) Do you agree?
 - (b) If not, do you think they should be shorter or longer?
- (4) Do you have a preference of overviews being presented using synthetic speech sounds, non-speech sounds (as shown in example) or a combination of both?
 - (a) Synthetic speech sound.

- (b) Non-speech sound.
- (c) Combination of both.
- (d) Depends on the application and context.

C DESIGN STUDY USER FEEDBACK SURVEY

Survey questions to obtain feedback on auditory route overviews as part of the Feedback Session of the Design Study (Section 4.3).

- Q1 Kindly listen to Design 1 and in a few words explain what you understood.
- Q2 The beeping sounds in Design 1 are actually representative of the turn numbers (re-affirmed by the speech sound), for example the third turn on left is shown by three beeping sounds in the left ear.
 - (a) Does having this information change your perspective about this design at all?
 - (b) Do these two overlain sounds increase or decrease the information provided?
 - (c) What are the good or useful features in this design?
 - (d) What are the bad or useless features in this design?
- Q3 Design 1 provides direction information while design 2 provides landscape information. Which one do you prefer and why? If you have no preference, please feel free to make any other comment you wish.
- Q4 Design 2 provides only landscape information, while Design 3 provides landscape information overlaid with direction information. Which one do you prefer and why? If you have no preference, please feel free to make any other comment you wish.
- Q5 Is there any scenario (or application) where you would prefer Design 1 over the other two designs?
- Q6 Is there any scenario (or application) where you would prefer Design 2 over the other two designs?
- Q7 Is there any scenario (or application) where you would prefer Design 3 over the other two designs?
- Q8 Kindly rate the difficulty level of the designs, in terms of understanding and retaining the information provided. The scale is 0 to 10, where, 0 is very easy and 10 is very hard.
- Q9 If you are not satisfied with the length of the display, how long do you think it should have been?
- Q10 Do you have any other suggestions for improving this design?

D SIGHTED PARTICIPANTS OF THE USABILITY STUDY

Name	Age	Gender	Proficiency	Sight classification
<i>PUS-s1</i>	27	F	N	S
<i>PUS-s2</i>	28	M	N	S
<i>PUS-s3</i>	25	F	N	S
<i>PUS-s4</i>	24	F	N	S
<i>PUS-s5</i>	32	M	N	S
<i>PUS-s6</i>	30	M	N	S
<i>PUS-s7</i>	30	F	N	S
<i>PUS-s8</i>	36	M	N	S
<i>PUS-s9</i>	28	M	N	S
<i>PUS-s10</i>	32	F	N	S
<i>PUS-s11</i>	31	M	N	S
<i>PUS-s12</i>	29	F	N	S
<i>PUS-s13</i>	25	F	N	S
<i>PUS-s14</i>	29	M	N	S
<i>PUS-s15</i>	27	M	I	S
<i>PUS-s16</i>	-	M	N	S
<i>PUS-s17</i>	26	F	N	S
<i>PUS-s18</i>	27	F	N	S
<i>PUS-s19</i>	27	F	N	S
<i>PUS-s20</i>	30	M	N	S
<i>PUS-s21</i>	44	F	N	S

Table 8. Table showing demographic information of the sighted participants

E SUPPLEMENTARY MATERIAL - AUDIO FILES

Sample designs from the Design Study

Please click the hyperlinks below to find the supplementary audio files. The files are hosted in SoundCloud.

- (1) Design 1
- (2) Design 2
- (3) Design 3

Usability study

Auditory Icons for the Usability Study. Auditory icons directory

Auditory Route Overviews used in Usability Study. Auditory route overviews directory

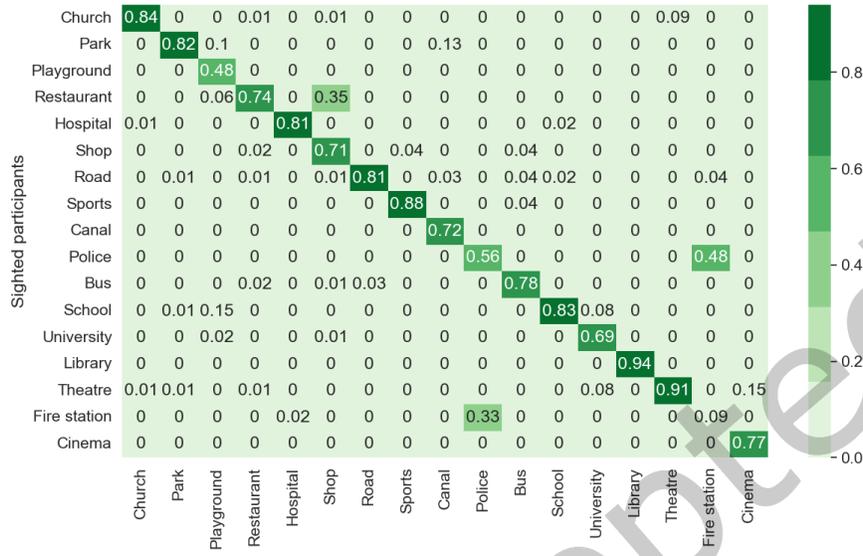
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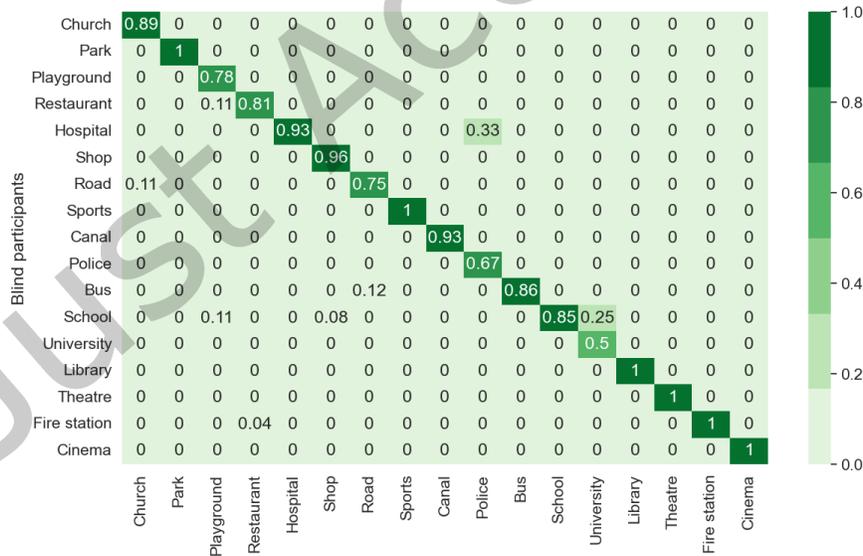
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(a) Responses of sighted participants



(b) Responses of blind participants

Fig. 16. Confusion matrix of identified Pols. Rows represent reference AIs and columns show participant responses

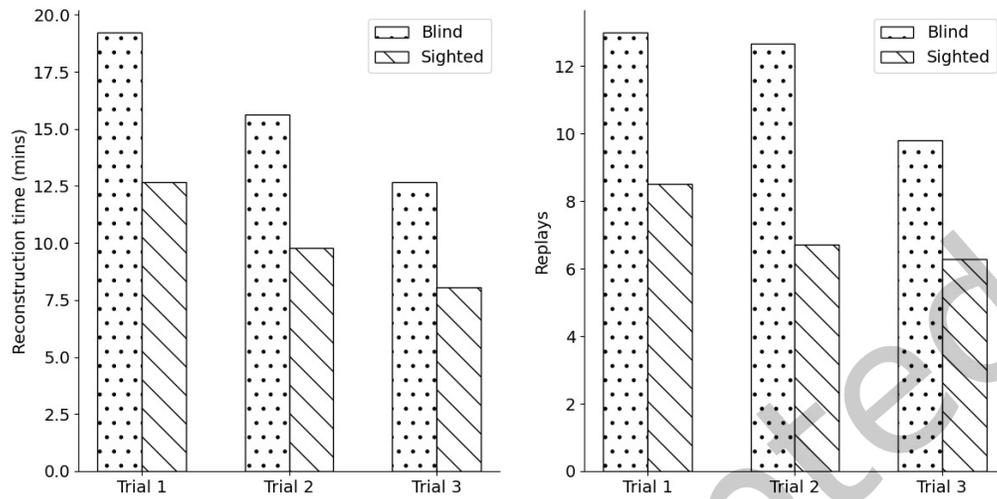


Fig. 17. Averages over trials. (a) Reconstruction time in minutes (b) Number of times auditory route overviews were replayed

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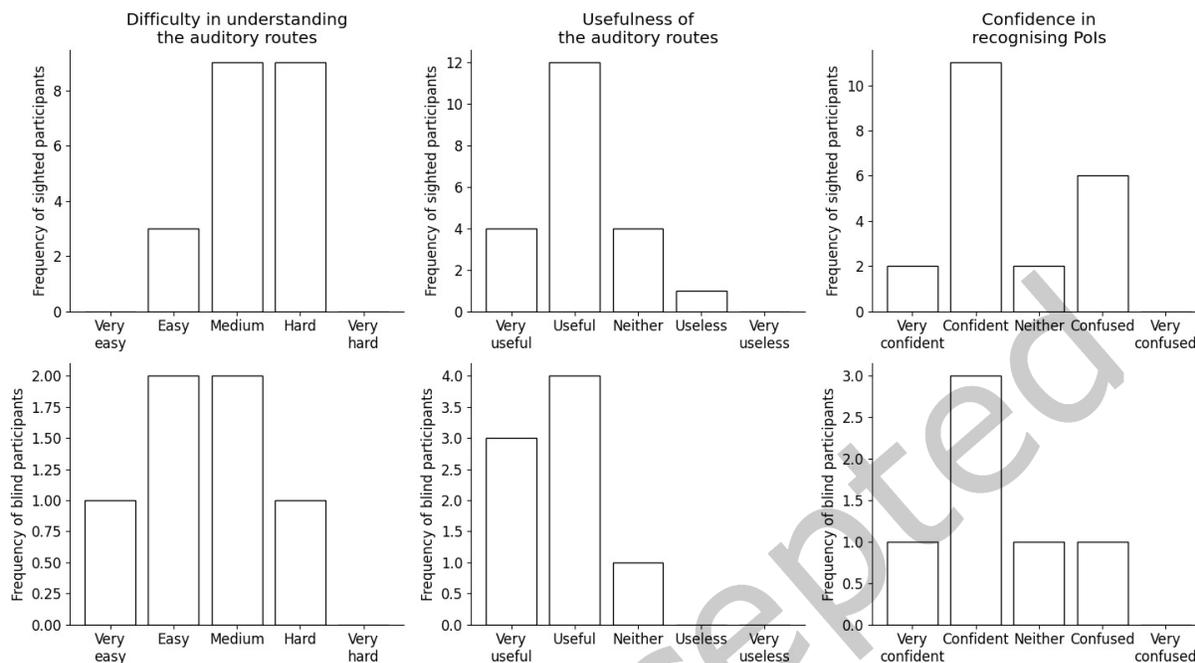


Fig. 18. Histograms of usability questions for sighted and blind participants: (a) shows the level of difficulty in understanding the auditory routes, (b) shows the level of perceived usefulness of the auditory routes, and (c) shows the level of confidence in understanding the auditory icons.