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# Audio-haptic mockups, audio diaries and participatory prototyping: Designing with and for people living with visual impairments

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Typical methods used to engage users in the design process often rely on visual techniques, such as paper prototypes, to facilitate the expression and communication of design ideas. The visual nature of these tools makes them inaccessible to people living with visual impairments. Additionally, while using visual means to express ideas for designing graphical interfaces is appropriate, it is harder to use them to articulate the design of non-visual displays. In this paper, we present an approach to conducting participatory design with people living with visual impairment incorporating various techniques to help make the design process accessible. We reflect on the benefits and challenges that we encountered when employing these techniques in the context of designing cross-modal interactive tools.

*Keywords:* Low-fi non-visual design, mock-ups, participatory prototyping, auditory display, haptic, tactile feedback, multimodal interaction, cross-modal interaction

## 1 Introduction

We are interested in the design of interactive tools that support collaboration between individuals who use different sets of modalities to interact with each other. We refer to this as *cross-modal interaction*. In this context, we have been exploring how to engage with people living with visual impairment to design interfaces that combine auditory, tactile and haptic displays to support accessible interaction in a variety of domains. Our work involves the participation of end user groups at various stages of the design process. First, when establishing an understanding of the challenges that people living with visual impairments face in environments where they collaborate with other people. Second, when generating and developing ideas for potential solutions to address such challenges, and finally when testing and evaluating developed solutions. This paper focuses on the former two levels of engagement with end users.

Naturally, solutions to addressing accessibility issues faced by visually-impaired users should be designed using non-visual modalities, such as audio, tactile and haptic displays. However, expressing design ideas that exploit these modalities is challenging. Unlike graphical designs, which can be drawn, edited and manipulated using low cost means, such as paper prototypes, it is harder to articulate, for example, how a particular shape or colour could be represented auditorally or haptically, or how to interact with an auditory or a tactile object. Additionally, involving visually-impaired users in the design process means that visual tools that are typically used in participatory design should be adapted to accommodate the particular needs of this population of users.

We developed and applied a participatory design approach that incorporates various techniques to help make the design process more accessible. We used basic audio recording equipments together with foam paper tags and electronic tag readers to construct low-fi physical audio-haptic mockups and deployed this technique to develop non-visual conceptual designs during initial idea generation workshops with

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visually-impaired users. We then combined participatory prototyping with audio diaries, where we presented visually-impaired users with highly malleable implementations of early prototypes through a series of workshops and involved them in iterative revisions of such digital prototypes as they gradually developed into fully functional designs. We ran participatory prototyping sessions across a number of weeks and asked participants to keep audio diaries of activity between each participatory prototyping workshop. This paper details our approach and discusses the benefits and challenges that resulted from employing these non-visual audio-haptic design techniques in combination with participatory prototyping.

## 2 Background & related work

### 2.1 *Cross-modal interaction*

Cross-modal interaction is fundamental to human perception and involves coordinating information received through multiple senses to establish meaning (cf. Spence and Driver 1997). An example of this is when we both see and hear someone talking and associate the words spoken with the speaker, thus combining information received from two signals through different senses. Cross-modal interaction design is therefore particularly relevant to individuals living with visual impairment who rely on sensory substitution to interact with visual artefacts. In the design of interactive systems, the phrase cross-modal interaction has also been used to refer to situations where individuals interact with each other while accessing a shared space through different modalities such as graphical displays and audio output (Winberg 2006, blinded for review view).

Despite significant progress in the use of the audio and haptic modalities in interaction design (McGookin and Brewster 2006), research into cross-modal interaction has so far remained sparse. Initial investigations in this area have nonetheless identified a number of issues that impact the design of cross-modal tools. For example, Winberg and Bowers (2004) examined interaction between sighted and visually impaired individuals on a puzzle game and highlighted the importance of providing visually impaired users with a continuous display of the status of the shared game. In another study, McGookin and Brewster (2007) used a system combining haptic devices with speech and non-speech auditory output to examine interaction between pairs of visually impaired users on graph reading tasks. Their results showed that the use of haptic mechanisms for monitoring activities and shared audio output improves communication and promotes collaboration. Although sparse, this body of work has highlighted the importance of supporting interactions involving individuals with differing perceptual abilities across various domains and generated insights into the knowledge that is needed to design effective support cross-modal interaction.

### 2.2 *Non-visual participatory design*

People living with visual impairments should be involved in the design of cross-modal interactive tools since they constitute one of the main user groups that can benefit from them. But as mentioned above, one of the challenges that designers face when co-designing with visually-impaired users is that typical participatory design tools and techniques, such as sorting cards and low-fi paper prototypes, are visual tools and so cannot be readily employed to accommodate the needs of this population of users.

A number of researchers have attempted to use alternative methods to overcome this issue (see Table 1 for a sample). For example, Okamoto (2009) used a scenario-based approaches as a means to enable rapid communication between stakeholders during workshop activities to help students understand the day-to-day activities of visually-impaired people and help them design tools to support them. Sahib *et al.* (2013) give a more thorough description of how scenario-based textual narrative can be tailored and used as a basis for design dialogue between a sighted designer and visually-impaired users. Sahib *et al.* (2013) also provide an evaluation of this approach, highlighting the importance of including visually-impaired users in the design process at two levels; first in the design of the scenarios themselves to ensure they include appropriate levels of description and use correct vocabulary that match the experience of visually-impaired people with current accessibility technology; and second when employing those scenarios in design sessions with visually-impaired users.

Table 1. Example approaches used to conduct non-visual participatory design.

| Modality | Technique & Materials | Domain |
|---|---|---|
| Speech-based | Scenarios, Narratives | Educational software, information seeking |
| Braille | Braille paper | General access to graphical user interfaces |
| Low-fi artefacts | Raised papers, pins & rubber bands | Instructional aids, learning to construct line graphs |
| Other tangible artefacts | Lego models, cardboard mock-ups, plastic | Haptic games, instructional aids |

Other approaches that proposed alternatives to visual design tools include the use of a tactile paper prototype which was developed as part of the HyperBraille project (Miao *et al.* 2009). In this project, a 120x60 two dimensional pin display is used to display multiple lines of text and graphics in combination with an audio display. Miao *et al.* (2009) present a set of recommendations for tactile paper prototyping based on Braille display to guide the design of haptic user interfaces. But using Braille technology to display text as a design tool might exclude visually-impaired users who are not Braille literate. Ramloll *et al.* (2000) used low-fi physical prototypes to explore how to design access to line graphs with visually-impaired school children. They used raised paper together with rubber bands and pins to explore how line graphs can be constructed non-visually. A workshop that ran as part of the NordiCHI conference in 2008 focused on developing guidelines for haptic low-fi prototyping (Brooke 2008), many of the suggestions made during that workshop can be used as part of an accessible participatory design process. For example, Magnusson and Rassmus-Gröhn (2008) describes the use lego models and technology examples together with scenarios to help give users first hand experience of designed tools, while Tanhua-Piiroinen and Raisamo (2008) described the use of tangible models, such as cardboard mockups and plastic models, to support early prototyping activities of accessible haptic and tactile displays. The main drawback of such tangible models are their static nature; once produced, it is hard to alter them in response to user feedback in real-time. Physical mockups are also naturally only suitable to prototype haptic interaction and do not adequately account for auditory interaction.

## 3 Approach

Figure 1 shows an overview of our approach to conducting participatory design with people living with visual impairments. At the core of this approach was an attempt to incorporate accessible means for designing auditory and haptic interaction by combining audio-haptic physical mock-ups with participatory prototyping and audio diaries. It is organised around two main stages, an initial exploratory workshop followed by a series of iterative participatory prototyping workshop sessions. We describe each stage in the following sections together with the accessible techniques we employed. We do this while referring to specific examples from two domains that we explored as part of designing cross-modal interactive tools. These domains are also described below.

### 3.1 *Participants & Setup*

We advertised a call for participation in the workshops in a number of specialised mailing lists for visually impaired professionals. We called for participants who specifically come across difficulties when engaging with sighted colleagues in their workplace due to the inaccessibility of tools they have available to them. We recruited the first 18 respondents (14 male and 4 female, mean age 47) who worked across a number of domains. Participants worked as educators and university teachers, software developers, musicians, charity workers, audio production specialists, sound engineers, and radio producers. All participants had no or very little sight, and all without exception used a speech or braille-based screen-reader to access information, and used a mobility aid such as a cane or a guide dog. All workshops were held at the authors' institution in an informal workspace and lasted for up to 5 hours each.

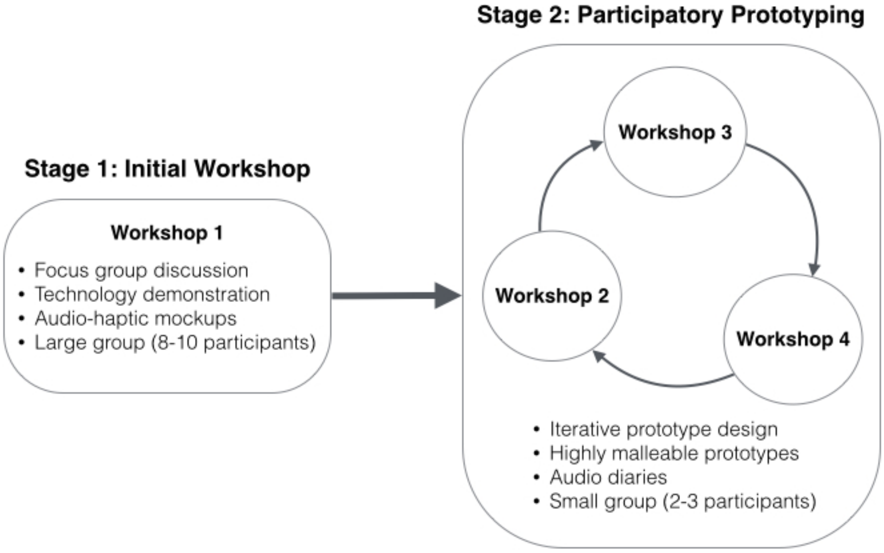


Figure 1. Overview of our approach to conducting accessible participatory design with people living with visual impairments.

### 3.2 *Design Domains*

We explored how to design for cross-modal interaction in the areas of diagram editing and music and sound production. Our choice of domains was based on the respondents areas of expertise as well as their immediate accessibility needs in these domains. People living with visual impairments rely primarily on screen-reader technology to access computer applications, but this technology falls short of providing adequate access to complex graphical representations such as diagrams or densely visual interfaces (see for example Figure 2). On the other hand, the ability to efficiently access and manipulate graphical representations can have significant impact on the day-to-day activities of visually-impaired people. For instance, participants in one of our workshops pointed out that being able to access and edit software engineering diagrams can be decisive in whether or not a visually-impaired engineer is promoted from a programmer to a systems analyst.

In the audio production industry, visually-impaired audio engineers and audio production specialists also rely on screen-reader technology to access digital audio workstations (DAWs), which are the main means for modern sound editing. But modern DAWs interfaces are highly visual and incorporate a number of graphical representations of sound to support editing and mastering, such as waveform representations, which are entirely inaccessible to screen-readers. Our participants pointed out that, in a competitive industry, the time it takes to overcome these accessibility barriers often hinders the ability to deliver projects in a timely manner and to effectively collaborate with sighted partners and hence can lead to the loss of business opportunities. In the area of diagram editing (henceforth referred to as the diagramming domain), screen-reader technology can access alternative textual descriptions – when these are available – which allow for a linear exploration of diagram content, the efficiency of which depends entirely on the quality of the description provided and the size of the diagram. We aimed to explore how to design audio and haptic interfaces that can provide visually-impaired users with direct access to diagrams, including the spatial arrangements of diagram content. In the area of sound editing (henceforth referred to as the DAWs domain), we aimed to explore how to design audio and haptic interfaces that provide effective access to the visual representations used to manipulate sound, namely waveforms.

### 3.3 *Stage 1: Initial workshop*

The first stage of our participatory design approach involves setting up an initial workshop with participants (8 to 10 participants per workshop) drawing from the network of users in the particular domain of focus. The initial workshops were organised around three main activities; focus group discussions, technology demonstrations, and audio-haptic mockups design.

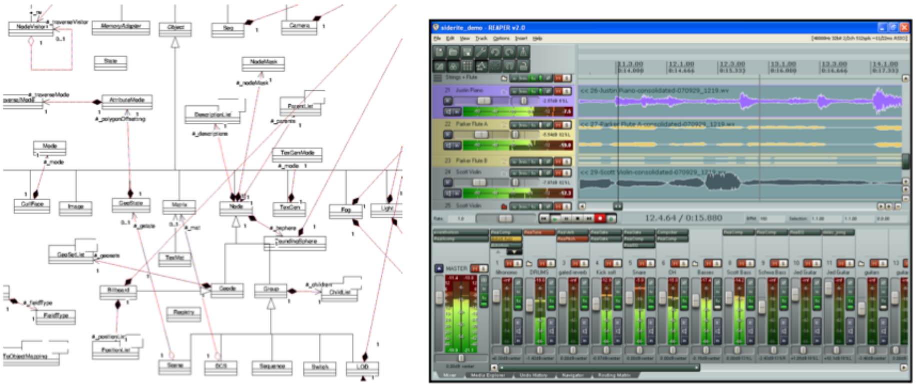

Figure 2. Example of a complex diagrammatic representation and a visually dense digital audio workstation interface.

**3.3.1** ***Focus group discussions.*** The workshop session was kick started with a group discussion involving both designers and participants. The discussion were structured around a number of topics to achieve the following aims:

- Establishing an understanding of current best practice in the domain under focus and how current accessibility technology supports it.
- Establishing an understanding of the limitations of current accessibility technology.
- Building consensus around a priority list of tasks that are either difficult or impossible to accomplish using current accessibility solutions and that participants would like to be accessible. The aim was to use the list of tasks to drive the participatory design parts of this initial workshops as well as set the direction for the whole project.

As an example of best practice, our participants made use of diagrams produced on swell paper, and used special geometry kit on which sighted colleagues can draw a raised version of a given diagram to show its main features. Participants highlighted that these static artefacts did not provide flexible and efficient independent access, particularly to support editing actions. In the DAWs domain, participants explained that screen-reader scripts were by far the most used accessible solutions, yet they remain inadequate when accessing waveform representations, applying sound effects, or navigating a large set of parameters space.

**3.3.2** ***Technology demonstration.*** In the second part of this initial workshop involved hands-on demonstrations of a range of accessible technology that could be used as a basis for designing better solutions to the identified limitations of current best practice. Depending on the number of participants, the availability of technology and the number of people from the design team present at a given workshop, technology demonstrations was done on either a one to one basis or in pairs. We found that visually-impaired participants are often very well aware of the state of the art in accessibility technology available but do not necessarily have direct access to or experience with all such technology. This part of the workshop provided an opportunity to explore the capabilities of some of these technologies through hands-on demonstrations, which helped participants gain more concrete ideas about what can be achieved with them.

In both domains, we demonstrated the capabilities of two haptic devices (a Phantom Omni[1] and a Falcon[2]), a multi-touch tablet, motorised faders, as well examples of sonification mappings and speech-based display of information (see Figure 3). We deliberately demonstrated the capabilities of a given technology without any reference to an actual application in order that the possibilities offered by the technology are not constrained by a specific domain or context. For example, in order to ensure an application-independent demonstration of the Phantom Omni and Falcon haptic devices, we used a custom program that allowed

[1]http://www.dentsable.com/haptic-phantom-omni.htm
[2]http://www.novint.com/index.php/novintfalcon

Figure 3. Some of the technology demonstrated in the initial workshop.

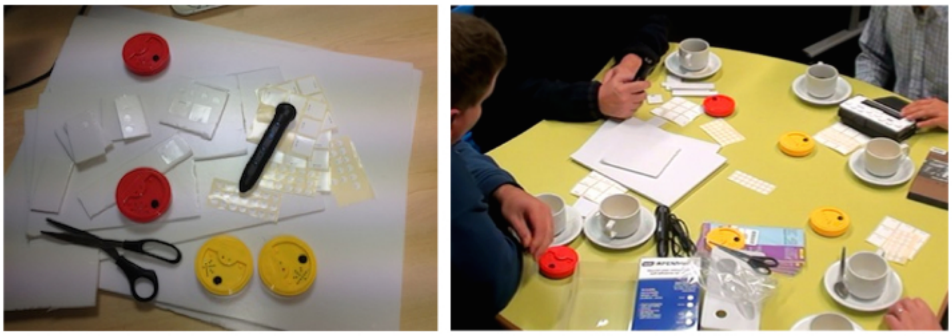

Figure 4. Foam paper, audio recorders, label tags and tag readers used to create low-fi audio-haptic mock-ups.

us to switch between different effects that could be simulated with these devices, such as vibration, spring effects and viscosity. The custom program allowed us to manipulate various parameters to demonstrate the range of representations and resolutions that could be achieved with each device in real-time. For example, a participant would manipulate a given device, while the designers triggered different virtual shapes, different haptic forces and textures and so on in response to the participant requests. The designers also presented additional features of the devices where these were not obvious to perceive. The pace and structure of the hands-on demonstrations were therefore jointly driven by the participants and the designers.

**3.3.3** ***Audio-haptic physical mock-up design.*** We invited participants to actively think through new designs in the last part of this initial workshop. Having had a hands-on experience with the capabilities of new technology, participants worked in small groups, with one to two design team members forming part of each group, and explored the design of a new interface that could be used to address some of the problematic tasks identified in the first part of the workshop. Participants were encouraged to think about how such tasks could be supported using some or all of the technology that they experienced through the demonstrations or how these could augment existing solutions to achieved better outcomes. This part of the initial workshop provided the opportunities for close collaboration between designers and participants. Members of the design team acted as both facilitators of the discussions that unfolded and contributed to refining the design ideas that were generated by the participants.

To help with this process, we attempted to use an accessible version of physical mock-up design (Beaudouin-Lafon and Mackay 2003). The material used to construct the physical mock-ups included foam paper, basic audio recorders, label tags an electronic tag readers (see Figure 4). Foam paper could be cut into various forms and shapes with the assistance of the sighted group member and used to build tangible haptic structures. Self adhesive tags could be attached to pieces of foam paper, which could then be associated with an audio description that can be both recorded and read using electronic tag readers. Additionally, basic audio recorders (the circular devices shown on Figure 4), which could recorded up to 20 seconds of audio, were provided to allow participants to record additional audio descriptions of their physical mock-ups. Thus, different pieces of auditorally labeled foam paper forms could be organised spatially and, if combined with the audio recording devices, could constitute physical low-fi semi-interactive audio-haptic mock-ups of an interface display or a flow of interaction. To close the session, participants were invited to present the physical audio-haptic mock-up they constructed with their group to the rest of the participants for further discussion.

In our design process, we used the outcomes of this initial workshop to construct digital prototype solutions embodying the ideas generated by out participants. We developed an audio-haptic diagram editing tool, and basic prototypes for scanning and editing sound waveforms. The details of these solutions are described elsewhere (*blinded for review*). These prototypes would then be used as a basis for driving the next stage in the design process, described in the next section.

### 3.4 *Stage 2: Participatory prototyping*

The second stage in our participatory design approach involved conducting a series of participatory prototyping workshops to engage users in an iterative design process that gradually develops fully functional designs. We invited smaller groups of participants (2 to 3 participants) who also took part in the initial workshops) to experience and actively contribute to the design of basic prototype implementations that embody the design ideas generated in the initial stage. We wanted to elicit the help of the same participants who were involved in the initial stage to ensure a continuity in terms of where the ideas were generated from and how these are to be further developed into concrete implementations.

Participatory prototyping activities in this stage had a number of important characteristics. First, rather than being exploratory in nature - as was the case in the first stage - activities at this stage were structured around the tasks that were identified as being problematic in the initial stage. The aim was to expose the participants to prototype designs that embody the ideas that were generated in the initial workshops of how such tasks could be supported, and to work closely with them to improve on the implementations of these ideas through iterative prototype development. Secondly, as opposed to the low-fi physical mock-ups used in the previous stage, the prototype implementations were developed into a highly malleable digital form. Thirdly, each set of participatory prototyping sessions were held with the same group of participants through a collection of three to four workshops that were one to two weeks apart. While the design team worked on implementing participants' feedback in the interim periods, participants were asked to keep detailed audio diaries of domain activities. These characteristics are described in more details below.

In these participatory prototyping sessions (see Figure 5), participants attempted to complete high level tasks while reflecting on the appropriateness of the features designed to support them. For example, participants used a sonification mapping that represented the peaks of a waveform to locate areas of interest within an audio track. The sonification mappings were based on ideas generated in the initial workshop, but could be manipulated programmatically in real time in response to participants' feedback.

**3.4.1** ***Highly malleable prototypes.*** The prototypes we developed to embody the design ideas generated in the initial stage of this approach were highly malleable because they supported a number of alternatives ways for presenting a given information or supporting a given task or functionality. The key to employing a highly malleable prototype in our approach is that it was easily customisable and alternatives are readily accessible in real time. We achieved this flexibility by developing specialised control panel, which we had available to us throughout the participatory prototyping sessions (see Figure 6). For example, in the DAWs domain, we developed a prototype controller that supports the scanning of a waveform representation by moving a proxy in a given direction and displaying a haptic effect whose main parameters are mapped to the data values represented by the waveform (e.g. amplitude mapped to friction and frequency mapped to texture; this is known as a haptification). This design was malleable in a number of ways; the direction of scanning could be altered to be horizontal or vertical and could be initiated at different starting points; the mapping used to drive the haptification of the waveform could also be adjusted in terms of scale and polarity; and finally, the haptic effects themselves could be altered to display, for instance, friction, vibration or viscosity.

The malleability of prototypes allowed visually-impaired participants to explore different implementa-

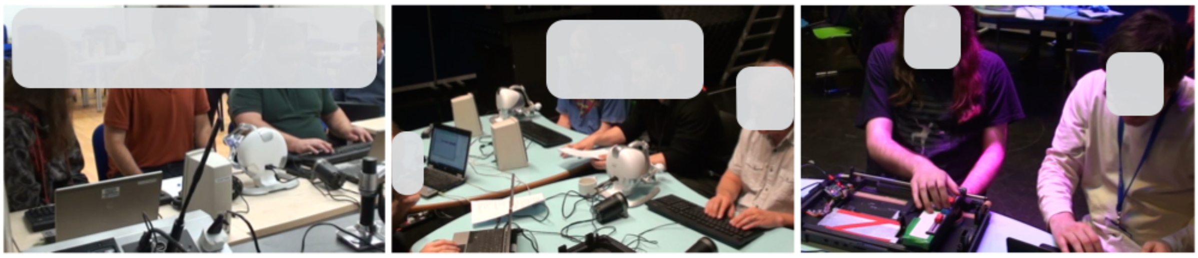

Figure 5. Participatory prototyping (blinded for review)

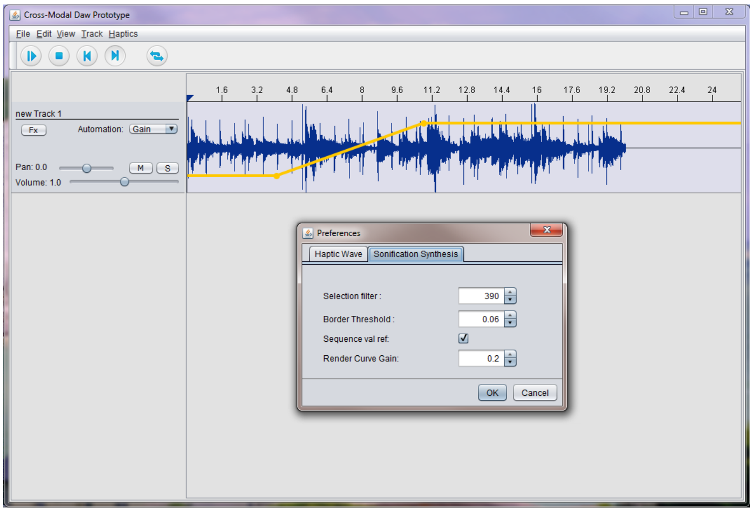


Figure 6. Example of a customisation panel

tions of the same functionality in real-time, which in turn facilitated the contrasting of ideas and the expression of more informed preference and feedback. Additionally, the prototypes could also be reprogrammed in real-time. That is, if participants wished to explore an alternative implementation of a given functionality or feature that could not be readily customised form the control panels, we reprogram these features on the fly as and when this was needed.

**3.4.2** ***Audio diaries.*** Another technique that we employed in this stage was to ask participants to record audio diaries in the interim periods that preceded each participatory prototyping session. Specifically, we asked participants to attempt to complete similar tasks to the ones explored during the sessions at their homes or workplaces. We asked them to do this while using their current accessibility technology set up and encouraged them to reflect on the process of completing these tasks in light of the particular iteration of prototype development that they were exposed to in the preceding participatory prototyping session.

Whenever participants produced an audio diary they would share it with the design team prior to the next prototyping session. This provided the designers with further feedback, thoughts and reflections that they could then incorporate in the next iteration of the prototypes and present to the participants in the next round of development.

## 4 Discussion

The participatory design approach we presented in this paper attempts to address the issues associated with the accessibility of a design process to people living with visual impairment. In particular, the approach emphasised the use of audio-haptic technology throughout the design process in order to facilitate discussions about audio and haptic percepts and help the envisioning and capturing of non-visual design ideas. Participants and designers brought different set of expertise to the sessions. In particular, participants had knowledge about the domain of their expertise but also in-depth knowledge about the practical limitations of current accessibility solutions. The workshop provided a number of opportunities for designers and participant s to collaborate.

We consider the two stages that constitute this approach to be complimentary in terms of the nature and aims of the activities they encompass. The initial stage was exploratory in nature and aimed to establish basic understandings of practice and technology before attempting to engage participants in generating and capturing broad design ideas. The second stage was more focused and addressed finer details of tasks and functionality in an iterative design process. Here, we reflect on the success and challenges of the various techniques used in each stage of our approach, these are summarised in Table 2.

### 4.1 *Reflections on Stage 1: Initial workshop*

This initial workshop was valuable in helping all participants (users and designers) establish a deeper understanding of context and possibilities. From the designers' perspective, this included learning about the issues faced by visually-impaired users, as well as when and where current technology failed to address those issues. From the users' perspective, this included encountering and understanding the capabilities of new technology, and hence new possibilities, as well as exchanging experiences with fellow users. In essence, only after each party learned more about these independent aspects (context and technological capabilities) were they then ready to move into a shared design space where they could effectively explore and generate design ideas together. The medium for this shared space in this case was the physical audio-haptic low-fi mock-ups.

**4.1.1** ***Benefits.*** The technology demonstrations were thus a valuable part of this initial stage. The benefits of demoing technology were twofolds. First, the demonstrations helped familiarise every participant with the technology that will be used to design potential solutions, which they may or may not have already come across. All participants could then engage in the design process with the same baseline of understanding and appreciation of possibilities. Second, the demonstrations helped in establishing a common vocabulary between designers and users that could then be used to express and communicate non-visual design ideas at later parts of the workshop. This exercise was particularly important for the haptic and tactile modalities. Unlike talking about auditory and visual stimuli, it is hard to talk about haptic and tactile experiences, and this lack of vocabulary has previously been found to hinder design activities (Obrist *et al.* 2013).

**4.1.2** ***Challenges.*** But not all the techniques used in this first stage of the design process achieved their expected outcomes and benefits. In the final part of this stage, we observed that participants attempted to use the material provided to create audio-haptic mock-ups but, as discussions unfolded, they drifted away from these material and focused on verbal descriptions only. In our experience, the less material participants used the more ideas they expressed. Thus, the process of constructing these mock-ups seems to have hindered rather than encouraged communication. What is interesting is that our audio-haptic mock-ups have had the opposite effect of their visual counterpart methods, where the use of mock-ups is often associated with engendering imagination and conversation (Brandt 2007).

While it is possible that training might change the situation, in general, one of the benefits of low-fi mock-up design activities lies in the fact that they require minimal training while yielding significant design insights. More training is therefore not necessarily desirable in this case. Another explanation for this is that visually impaired users do not see the construction of the physical prototype in the same moment as it is being constructed and so the process lacks the emergent properties and illuminating qualities that it can have when shared by sighted co-designers. That is, the audio-haptic mock-ups no longer functioned as a shared artefact unless explicitly passed around, which may have contributed to decreasing the spontaneity that the visual counterpart process has. Indeed, the use of the physical mock-ups might have contributed to creating an asymmetry between the contributions of the sighted designers – who could not only see the

Table 2. Effectiveness of techniques used in participatory design with visually-impaired users

| Technique | Design stage | Advantages / Disadvantages |
|---|---|---|
| Focus group discussions | Initial workshop | Established deeper understanding of context and technological capabilities. |
| Technology demonstrations | Initial workshop | Built common knowledge about possibilities and shared vocabulary. |
| Audio-haptic mock-ups | Initial workshop | Hindered communication and broke spontaneity of shared experience. |
| Highly malleable prototypes | Participatory prototyping | Facilitated joint learning experience and finer scrutiny of detailed design. |
| Audio diaries | Participatory prototyping | Expanded reflection space and provided access to in-situ experiences. |

physical artefacts but also assist with their construction – and that on the visually impaired participants. In this sense, the shift away from the physical artefacts to the verbal descriptions would have contributed to balancing this asymmetry between designers and participants since all parties were then using a modality that could be equally shared amongst everyone.

Another possible explanation for this observation is indeed the type of users we worked with. Visually-impaired users are perhaps used to talking about their experiences descriptively and so do not have the same need as other end user groups to be explicitly encouraged to express design ideas. Another possibility is that the tasks that users were trying to design for were too complex to be captured using the low-fi material provided. Our observations are nonetheless inline with previous work that found narrative scenario-based design to be a particularly effective tool to use with visually-impaired participants (Okamoto 2009, Sahib *et al.* 2013). Still, thorough comparisons of these different methods for non-visual participatory design is lacking and more studies are needed to further investigate these issues.

### 4.2 *Reflections on stage 2: Participatory Prototyping*

The collection of participatory prototyping workshops that we held in the second stage of our process were valuable in helping us delve deeper into the design of the developed solutions. These sessions were an opportunity to collectively scrutinise finer aspects of design and thus provided a further joint learning space where participants learn more about the technology and the techniques, e.g. sonification mappings, and designers learn about detailed workflows and processes. The small number of participants in these sessions helped achieved higher degrees of detailed scrutiny (with sessions often lasting up to 5 hours). The medium for facilitating participatory prototyping in this space were the highly malleable prototypes.

**4.2.1** ***Benefits.*** The malleability of these digital prototypes was critical in ensuring the success of the participatory prototyping sessions. Being able to present participants with different alternatives and reprogram features on the fly captured an essential characteristic that is found in, for example, paper prototyping techniques that make them an extremely effective design tool (Beaudouin-Lafon and Mackay 2003). The prototypes capacity to be adaptable in response to changes and feedback generated from the joint prototyping process is crucial in prototyping activities (Kyng 1991), and non-visual design tools should therefore incorporate flexible levels of adaptability for them to attain the same level of efficiency as their visual counterparts. While this was not true in our experience with using the physical audio-haptic mock-ups, which hindered rather than nurtured communication and exchange of design ideas, digital implementations of highly malleable prototypes afforded a more supportive medium of communication between participants and designers.

The use of audio diaries was also valuable in a number of ways; first, they expanded the space of reflection on designs to reach beyond the bounds of participatory sessions themselves. Participants were able to go back to their home or workplace settings, re-experience the tasks with their own technology, compare this to what they have experienced with the new prototypes and record these reflections on an audio diary. Secondly, audio diaries provided the designers with an extra resource of feedback, it gave the designers access to actual in-situ experiences with current accessibility solutions – often these were screen-reader based technologies, and so the audio diaries capture both participants commentary and the interface interactions in speech. Users provided running commentary, explaining rational for certain interactions, issues and potential solutions to them in light of their experience in the initial workshop session and the participatory prototyping sessions. Audio diaries thus give direct access to actual experiences with accessibility technology that would have been harder to tap into otherwise.

## 5 Conclusion

We presented an approach to conducting participatory design with visually-impaired users that incorporates accessible means for expressing and communicating non-visual design ideas. This approach emphasised the need to use non-visual technology throughout the design process in order to build shared vocabularies and support effective expression, communication and capture of design ideas. Our approach combined an initial stage involving focused discussions, application-independent technology demonstrations and non-visual design activities, with a second stage of iterative participatory prototyping sessions that rely on highly malleable non-visual prototypes and audio diaries. We reflected on the benefits and challenges that we experienced when applying this approach. In particular, non-visual technology demonstrations allowed us to establish a baseline of shared understanding and to build a shared vocabulary for expressing non-visual design ideas, while low-fi physical audio-haptic mock-ups did not encourage co-design as anticipated and instead hindered communication. Participants switched to verbal descriptions to generate and capture design ideas instead. The use of highly malleable non-visual digital prototypes in the second stage provided an effective medium for shared design activities, while audio diaries expanded the users' reflection space to reach beyond design sessions and provided designers with a further resource of feedback.

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