TOWARDS SONIFICATION FOR ACCESSIBILITY IN PUBLIC TRANSPORT

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ABSTRACT

Traveling by public transport can be challenging for visually impaired travelers. However, visual information can be supplemented by sonification–the use of non-speech sound to convey data. This ongoing research project aims to explore how sonification can be used to provide information to travelers at a bus stop. The distance between an approaching bus and the bus stop, as well as the position of the front and middle doors, was sonified. The sonification design used parameter mapping, and an earcon was used to indicate that the bus had arrived. The sonification design was supported by the outcome of two online user surveys, and explored through interviews with visually impaired participants.

1. INTRODUCTION

Although visualization is a widely used method for conveying data, it can sometimes be ineffective. Various visual perception challenges, such as simultaneous brightness contrast [1] and the Mach band phenomenon [2], can affect how visual representations are perceived and interpreted [3, 4]. Additionally, poor lighting conditions or limited fields of view can hinder the effective communication of visual information. Furthermore, individuals with visual impairments, such as reduced visual acuity or color vision deficiencies, may find it difficult or even impossible to accurately perceive visual representations. The challenges associated with visualization and visual perception can be addressed by complementing it with sonification. Sonification, the use of non-speech sounds to represent data, can enhance the perception and understanding of visual representations [5, 6].

Public transportation is a crucial means of mobility for many individuals in society. Every day, numerous people take the bus to work, school, social gatherings, leisure activities, and various events. However, accessibility in public transportation is not evenly distributed, which becomes particularly evident when unexpected changes occur, such as a relocated bus stop or platform. For travelers with visual impairments, interpreting these new situations can be challenging due to limited access to information. A preliminary study conducted by Östgötatrafiken[1], a public transportation company in Sweden, suggests that the overall sound environment in and around vehicles should be further developed and improved to support accessibility. However, it remains unclear how sound can best be utilized for this purpose–what should be sonified, when should it be sonified, and what types of sounds should be used.

In this research, we aim to explore how sonification can improve accessibility in public transportation by designing relevant sonification and auditory information to enhance the travel experience for visually impaired individuals. This paper presents the introductory explorations of sonification design approaches and data mapping strategies for sonifying in relation to public transportation. We hope that by integrating sonification, accessibility in public transportation can be significantly improved.

The research team includes experts in sonification and urban and construction logistics from Linköping University, representatives from Gaia–an IT company specializing in real-time transport network analysis–a traffic planner from the municipality of Norrköping, representatives from Östgötatrafiken, the regional public transportation operator, and a representative from an advocacy organization for individuals with visual impairments.

2. RELATED WORK

Sonification has been explored as a support for the visually impaired in several studies (see for example [7, 8, 9]). Some studies have suggested that using sonification as a support for visual perception is beneficial for individuals with normal or corrected to normal visual acuity [10, 11, 12], and that sonification can reduce cognitive load [13] on the visual modality [14]. Other studies have shown interesting results on the combination of visual and auditory designs for audio-visual alarms for supervision tasks [15] and monitoring [16].

The combination of visualization and sonification has also been explored [17, 18, 19], and should lead more effective multimodal representations as compared to when using visual stimuli alone [20]. There are several studies that evaluate visualization and sonification as a combination [21, 22, 23, 24, 25, 26, 27], and these suggest that there is a benefit of the combination. As a more specific example, sonification can be used to facilitate perception of density levels in scatter plots and parallel coordinates [28].

Sonification has also been proven to be a support for the visually impaired [29], by supporting perception of visual representations [30], and supporting perception of visualization by using sounds mapped to bar charts and line charts [31], and also supporting interpretation of visualization and text information [32]. Sonification has furthermore been demonstrated to be able to support visually impaired individuals in avoiding obstacles [33, 34], in crossing roads [35] and in navigation [36, 37], in guidance of manual tasks [38], in perception of complex systems [39], and in supporting the use of educational games [40].

[1]an internal investigation and pre-study performed by the public transportation company

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Some research have studied the use of sound in relation to automated vehicles [41], autonomous buses [42], and rail transit [43]. Some studies have explored sonification for electric vehicles [44], and for public transportation to make understanding of transportation systems more easy [45]. However, we have not been able to find research on sonification for public transport for the visually impaired.

3. INTRODUCTORY SONIFICATION DESIGN EXPLORATION

The work was performed in several iterative steps where the initial ideas for sonification were explored within the research team. Different sonification designs were quantitatively evaluated in two online surveys to get a broader participant base for refining the sonification design, which in turn was followed by a qualitative evaluation with individuals with visual impairment.

Sonification presents some challenges compared to visualization in terms of simple methods for sketching and co-design. To facilitate discussions on different sonification approaches and designs within the research team, a simple, cartoon-like demonstration was created. The purpose of using a cartoon-like visual style is to emphasize that this is a demonstration rather than a final representation of the sonification design (see more in [46]).

The sonification concepts primarily involved *parameter mapping sonification*, which refers to the association of data values with auditory parameters such as pitch or loudness [47], where the sound output depends on the mapping function between the data and the auditory parameters. Some of the sonification concepts included short, distinctive musical sounds that represented specific events; these are called *earcons* [48]. These sounds can be described as sound symbols and require prior knowledge of what the sound represents to be effectively used.

These simple demonstrators facilitated the discussions within the research team about the wide range of sonification approaches that could be explored, including sound level, pitch, tempo, chords (or harmony), melodic movements, timbre, and rhythm. Based on these initial concepts and discussions within the research team, the following two situations were selected for the continued sonification design work: 1) Sonification of the distance between the arriving bus and the bus stop (see Figure 1), and 2) Sonification of the position of the bus doors (see Figure 2).

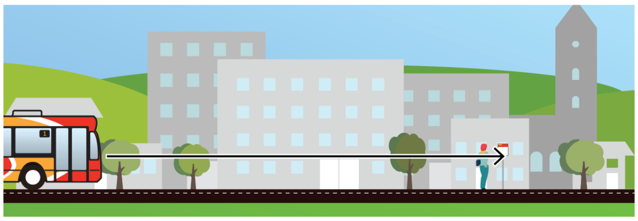

Figure 1: Sonification of the distance between bus and bus stop.

4. FIRST ONLINE USER SURVEY

The first online user survey explored different sonification approaches for representing a decreasing distance between an arriving bus and the bus stop, as well as for indicating that the bus had arrived at the bus stop.

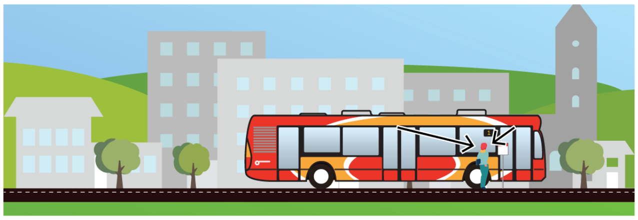

Figure 2: Sonification of the position of the middle and the front doors in relation to the traveler.

4.1. Sonification design

For sonifying the distance, three different sonification approaches were selected based on initial discussions within the research team. The auditory parameters mapped to the distance were sound *level*, *pitch*, and *tempo*. To indicate that the bus had arrived at the bus stop, *earcons* were used, consisting of either a single tone or different melodic movements.

All sonification designs were created in SuperCollider, a real-time sound synthesis coding environment [49]. In SuperCollider, synth definitions were used to generate the sound. These consisted of triangle oscillators, producing a relatively soft yet engaging sound (see Figure 3). The initial frequencies of these were 174.61 Hz (F), 220 Hz (A), 261.63 Hz (C), and 349.23 Hz (F). The frequency of these oscillators (the perceived *pitch*) was controlled by the distance data through a linear-to-exponential mapping. The output of the oscillators was summed and sent to an output amplifier, and the sound *Level* could also be controlled by the distance data using a linear-to-exponential mapping, from fully attenuated to no attenuation. Additionally, a pulse wave oscillator controlled the gate of a percussive envelope generator, creating amplitude modulation of the sound from the triangle oscillators. The frequency (i.e., *tempo*) of this amplitude modulation was also mapped linearly to exponentially to the distance, creating a tremolo like effect where the sound was attenuated periodically. These sonification approaches was explored individually as well as in combinations.

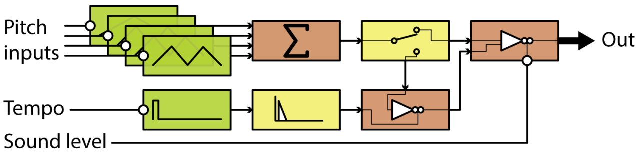

Figure 3: The sonification design was made in SuperCollider, and consisted of triangle oscillators creating the sound. The pitch of these could be controlled as well as the output sound level, also the tempo of a envelope generator could be controlled creating a amplitude modulation.

These sonification designs were also tested in different combinations to determine whether there was a perceived benefit from using multiple auditory parameters simultaneously. The following sonification designs were explored: 1) sound level, 2) pitch, 3) tempo, 4) sound level & pitch, 5) sound level & tempo, 6) pitch & tempo, 7) sound level & pitch & tempo. In this way all sonification designs were explored in every possible configuration.

The earcon used to represent that the bus had arrived was also created in a similar way with a triangle oscillator, and a bell-like amplitude envelope. The earcon had three different designs: 1) a *Single* tone, 2) an *Upwards* going three tone melody, and 3) a *Downwards* going three tone melody (see Figure 4). The single tone used the tone F (698.46 Hz), and the upwards going melody used the tones A (440 Hz), C (523.25 Hz), and F (698.46 Hz). The downwards going melody used the tones C (523.25 Hz), A (440 Hz), and F (349.23 Hz).

Figure 4: The earcons used for sonifying that the bus had arrived was either a *Single* tone, an *Upwards* or *Downwards* going melody.

4.2. Method

The online survey took approximately 10 minutes to complete. Participants listened to different examples of the sonification and then rated their experience. The survey explored both the sonification of the distance between the bus and the bus stop, as well as the earcons used to indicate that the bus had arrived. No visual information, such as distance indicators or animations of an arriving bus, was provided–only auditory representations were used.

The survey first provided general information about the test and asked participants to sit in a calm environment, use headphones, and adjust the sound level to a comfortable level. The test then presented three sounds, allowing participants to explore them in any order and replay them if needed. For each sound, two questions were asked: one about how well the sound represented the decreased distance and another about how pleasant the sound was perceived to be. These questions were answered using a 5-point Likert scale ranging from "Very poor" to "Excellent".

Finally, participants were asked two additional questions: which sound was most helpful in understanding that the distance was decreasing and which sound they preferred. Responses were given by selecting one of the three sounds or choosing "No opinion". This process was repeated for all combinations of the sonification designs. For the earcons, the questions were adjusted to refer to the arrival of the bus rather than the distance.

Participants were recruited through various social media platforms. 37 participants with normal or corrected to normal visual acuity, completed the survey. As the aim of the survey of was to find support for design decisions based on a broader participant base, no other information about the participants was recorded.

4.3. Results

The Likert scale data from the user survey was analyzed Using IBM SPSS 29. As the data was not normal distributed, Friedman's test was used for the statistical analysis and post-hoc tests were done using Wilcoxon signed-rank test using Bonferroni correction for multiple comparisons.

There was a statistically significant difference in how well the sonification designs were experienced to represent a decreasing distance, $\chi^2(8) = 73.47, p < 0.001$ (see Figure 5). Post-hoc tests were done for the sonification designs with the highest rankings *tempo* when only one auditory parameter was used in the sonification design (blue background), *tempo and sound level* when combinations of two auditory parameters were used (yellow background), and *sound level & tempo* when one, two, and

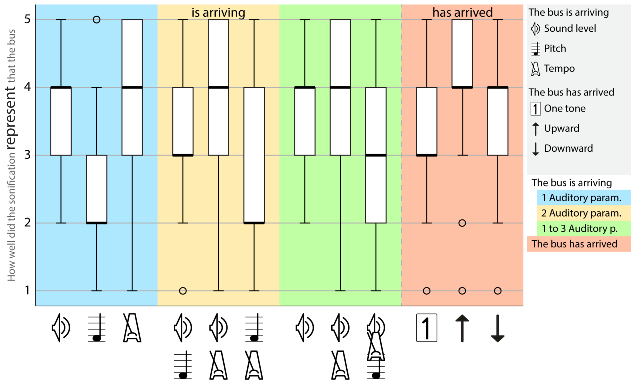

Figure 5: Boxplot showing how well the sonification designs were experienced to represent the approaching bus (blue, yellow, and green background) or that the bus had arrived (red background).

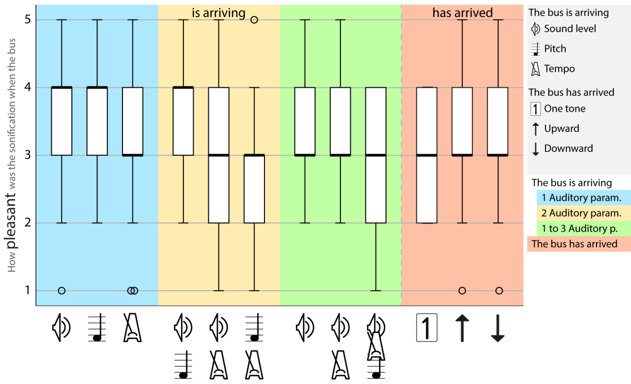

Figure 6: Boxplot showing how pleasant the sonification designs were experienced: approaching bus (blue, yellow, and green background) or that the bus had arrived (red background).

up to all three auditory parameters were used (green background). The post-hoc test showed significant differences for both of the combinations compared to *tempo* ($Z = -2.13, p = 0.033$, and $Z = -2.31, p = 0.021$) where the combinations were rated as better in representing a decreasing distance, but there were no significant difference between the two versions of the combination ($Z = -0.54, p = 0.593$). There was also a statistically significant difference in which earcon design that was experienced as best representing that the bus had arrived, $\chi^2(2) = 14.95, p < 0.001$, and post-hoc tests showed that the *Upwards* going melodic movement was rated as more representative than the others ($Z = -3.25, p < .001$, and $Z = -2.74, p = 0.006$).

Furthermore, there was a statistically significant difference in how pleasant the sonification designs were experienced, $\chi^2(8) = 34.97, p < 0.001$ (see Figure 6). Post-hoc tests showed significant differences for the combination of *sound level & tempo*, *pitch & tempo*, and *sound level & pitch & tempo* that were rated as less pleasant than the other sonification designs ($Z = -2.29, p = .022$, $Z = -4.02, p < 0.001$, and $Z = -2.64, p = .008$). There was also a statistically significant difference in how pleasant the earcon design was experienced, $\chi^2(2) = 6.53, p = 0.038$. Post-hoc tests suggested that the *Upwards* was experienced as more pleasant than the *Single* tone ($Z = -2.79, p = .005$).

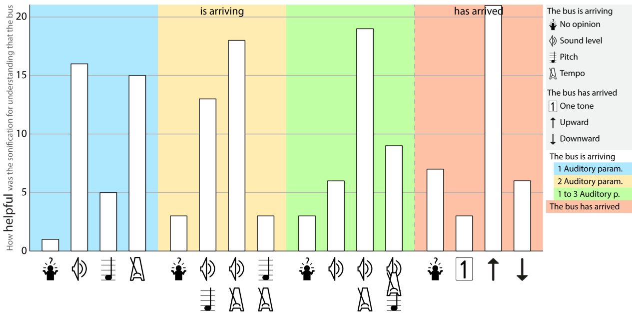

Figure 7: Histogram showing how helpful the sonification designs were experienced for the approaching bus (blue, yellow, and green background) or that the bus had arrived (red background).

The helpfulness and the preference for the sonification design was analyzed by counting the rankings, and using histograms. For the sonification designs for the decreased distance *sound level*, *tempo*, and the combination of these two auditory parameters were in general experienced as most helpful (see Figure 7). This was also the case for the *Upwards* going melody. In general, *tempo* and the combination of *sound level and tempo*, but also the combination of *sound level and pitch* were the preferred sonification designs for the representing the decreased distance (see Figure 8), as well was the *Upwards* going melodic movement.

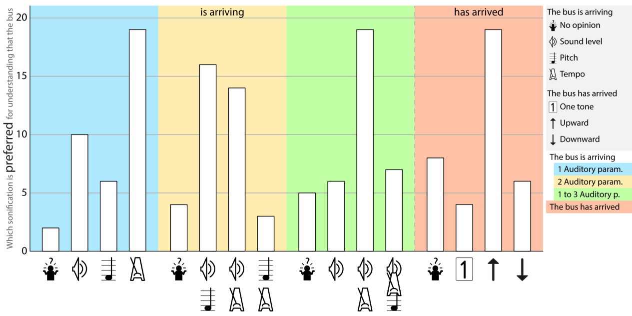

Figure 8: Histogram showing which of the sonification designs that were preferred for the approaching bus (blue, yellow, and green background) or that the bus had arrived (red background).

4.4. Reflection

The sonification approaches that were perceived as best representing the decreasing distance between the bus and the bus stop were *tempo* and the combination of *sound level* and *tempo*. In general, there were no major differences in the perceived pleasantness of the sonification designs, suggesting that they were equally pleasant. The ratings for helpfulness and preferred sonification design indicated that the combination of *sound level* and *tempo* was the most effective. Using both auditory parameters together can provide meaningful auditory information to users, as mapping multiple auditory parameters to data may enhance understanding [50]. This makes it reasonable to continue exploring sonification for accessibility in public transportation using this combination.

5. SECOND ONLINE USER SURVEY

The second online user survey explored different sonification approaches for representing different door positions on a bus.

5.1. Sonification design

The position of the front door and the middle door was sonified using three different parameter mapping approaches. The auditory parameters used to represent the different doors were *pitch*, *rhythm*, and *timbre*.

These sonification designs were explored by mimicking the experience of standing next to the bus, with the doors (i.e., the sonifications) positioned relative to where the user might be standing (see Figure 9). This was achieved by adjusting the sound level of the sonifications to reflect the distance to the doors and using stereo panning to represent their relative positions. The positions explored was 90% and 10% panning to the doors, 75% and 25% panning to the doors, and equal panning (50%) to both doors. The sound level of the sonifications was adjusted accordingly.

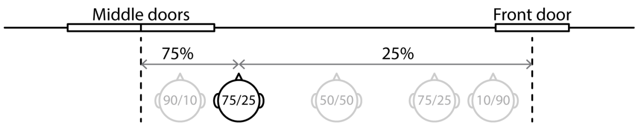

Figure 9: The position of the doors was created by stereo panning and sound level adjustments. In this example the listeners position is 75% closer to the middle door compare to the front door.

As in the first online user survey, SuperCollider was used for all sonification designs. In SuperCollider, different synth definitions were created for the various sonification approaches. Common to all of these was an output module with sound level and stereo panning adjustments.

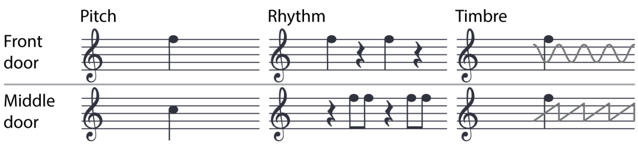

Figure 10: The three sonification designs for the positions of the doors, utilizing *pitch*, *rhythm*, and *timbre*.

The sonification that utilized *pitch* to represent the doors consisted of a sine wave oscillator. The front door was sonified with an F (698.46 Hz), and the middle door was sonified with a C (523.25 Hz) (see Figure 10). The sonification approach that used *rhythm* employed sine wave oscillators at the same pitch but with different rhythms (while maintaining the same tempo), where one pulse represented the front door and two pulses represented the middle door. Finally, the sonification design that used *timbre* featured one sine wave oscillator and one sawtooth oscillator at the same pitch, with their sound levels adjusted to be perceived as equally loud. These sonification approaches were explored individually as well as in combination.

5.2. Method

In total, 36 participants with normal or corrected to normal visual acuity were recruited through social media platforms. No other information about the participants was recorded–only their responses to the sonification design.

In the survey, participants listened to the sonification of the two positions as well as a combined sound representing both positions. They could listen to these sounds in any order and replay them as needed. This was followed by a task in which participants listened to a sound featuring the sonification of both doors and indicated which door position was perceived as the closest (choosing between door 1, door 2, or equal). Next, they rated the difficulty of the task on a 5-point Likert scale ranging from "Very hard" to "Very easy". Each sonification design–*pitch*, *rhythm*, and *timbre*–was tested across five tasks, using the different stereo panning to simulate various positions. After completing each set of five tasks, participants rated how well the sonification design represented the different positions and how pleasant the sonification was perceived to be, similar to the first online user study.

The survey then continued by presenting all three sonification designs, and participants were asked to rank them based on which sonification was the most helpful and which was preferred (in the same manner as in the first online survey). This was done for all combinations of sonification.

5.3. Results

The data from the user survey was analyzed using the same statistical methods as for the first user survey. There were no significant differences found in how hard it was to use the sonification design in experiencing the position, $\chi^2(2) = 3.15, p = 0.206$ (see Figure 11). There was a significant difference in how well the sonifications represented position, $\chi^2(2) = 12.06, p = 0.002$, and post-hoc tests showed that *rhythm* was rated higher compared to *pitch* ($Z = -2.44, p = .015$) and compared to *timbre* ($Z = -3.15, p = .002$), but there were no significant differences found between *pitch* and *timbre*. A significant difference was also found in how pleasant the sonifications were experienced, $\chi^2(2) = 49.19, p < 0.001$, and post-hoc tests suggested that *rhythm* was experienced as more pleasant than *pitch* and *timbre* ($Z = -4.37, p < .001$, and $Z = -5.11, p < .001$), and that *pitch* was more pleasant than *timbre* ($Z = -3.20, p = .001$).

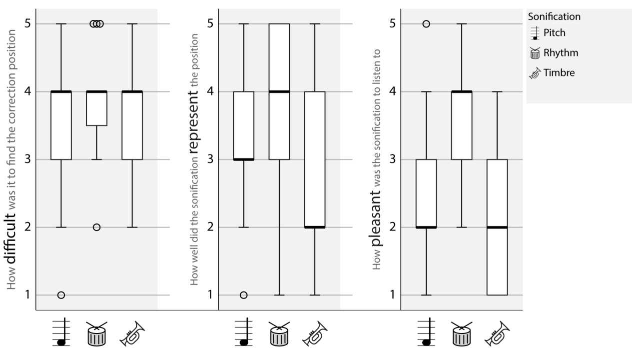

Figure 11: Boxplots showing the difficulty of using the sonification designs, how well these represented positions, and how pleasant these were experienced.

The analysis of the helpfulness and the preference for the sonification designs suggested that *rhythm* and the combination of *rhythm* and *pitch* were experienced as most helpful (see Figure 12)

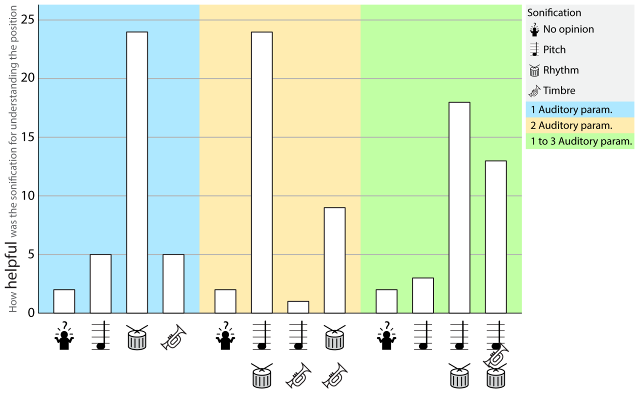

Figure 12: Histogram showing how helpful the sonification designs were experienced for perceiving the position of the doors.

as well as experienced as preferred (see Figure 13) for sonifying the position of the bus doors.

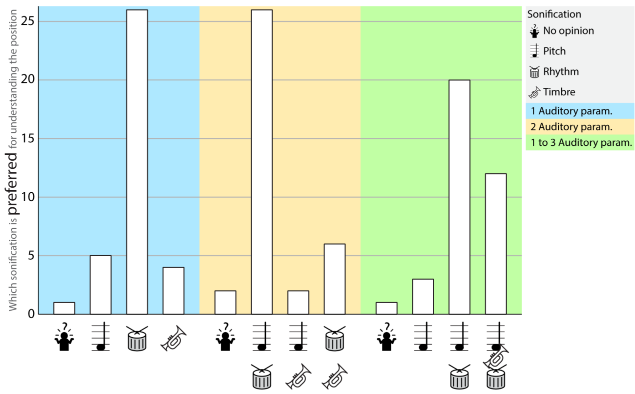

Figure 13: Histogram showing which of the sonification designs that were preferred for representing the positions of the doors.

5.4. Reflection

All sonification approaches appeared to be useful and, in general, equally easy to use for perceiving the position of the doors. However, *rhythm* was preferred and perceived as more pleasant compared to the other auditory parameters used in the sonifications. The use of *rhythm*, as well as the combination of *rhythm* and *pitch*, was generally ranked as the most helpful and preferred. Previous research [50, 47] has suggested that combining auditory parameters in parameter-mapping sonification can be beneficial. This, along with the results of the second user survey, suggests that the combination of *pitch* and *rhythm* should be explored further for accessibility in public transportation.

6. QUALITATIVE USER EVALUATION

The qualitative user evaluation combined insights from the two online user surveys and explored the sonification design with individuals with visual impairments or vision loss.

Three soundscapes were created using sound recordings of a bus arriving at a bus stop in three different environments: 1) a calm and quite rural setting, 2) a relatively quiet town, and 3) a busy city. Two versions of each sound were produced–one without sonification and one with sonification. The sonification design was based on findings from the two online user surveys and used *sound level* and *tempo* to represent the decreasing distance between the bus and the bus stop, but was designed and synchronized to the arriving bus using synthesizers in a digital audio workstation. The sonification design also used the *Upwards* going melodic movement to represent that the bus has arrived at the bus stop. Additionally, three extra sounds were created, one for each environment. In these, the doors (front and middle) were sonified with slight variations in the listeners position between the doors.

The user evaluation used semi-structured interviews to understand whether sonification could enhance accessibility in public transportation in general, if sonification of the distance and the positions could be helpful, and how the overall sonification design was experienced. Participants first listened to a soundscape without sonification, followed by the same soundscape with sonification, using headphones in a calm environment. After this, a discussion about the sonification design took place. Once all three environments had been presented and discussed, the sonification of the doors was explored. A general conversation about sonification for accessibility in public transportation concluded the evaluation.

Four participants, two male and two female, with an mean age of 72 (range 66 to 80 years) took part in the evaluation. All participants were blind, and had been blind for at least ten years.

6.1. Outcome and Reflection

The soundscapes were perceived as realistic and representative of the everyday experiences of a blind person. They were also experienced as progressively noisier and louder environments. The idea of sonifying the distance between the bus and the bus stop, as well as the position of the doors, was considered useful and helpful. The sonification aided in hearing the arriving bus which would help in preparing to enter the bus, and in locating the direction to the doors which should aid in finding the right door when entering the bus. In the rural soundscape, the sonification was not perceived as particularly helpful compared to the noisier and more dynamic city soundscapes. As noise levels increased, the usefulness of the sonification was also perceived to increase.

Although the sonification design was perceived as useful and helpful, the sound design could be improved. The mapping approaches were considered effective, but the increase in tempo as the bus approached the bus stop was experienced as becoming too fast, making the sound feel stressful. In contrast, the sonification of the door position was perceived as pleasant and effective, allowing it to stand out among other environmental sounds in the soundscape. One participant noted that while the sound might feel somewhat stressful, it was still useful, and that greater familiarity with the sonification might reduce this perception over time.

7. DISCUSSION AND FUTURE WORK

The research described in this paper can be seen as an initial exploration of sonification for accessibility in public transportation and will be further developed with new design ideas to investigate.

The sonification design explored in this study appears to be useful for its intended purpose. However, further refinement and improvement of the sound design are necessary. Part of this work will involve adjusting the mapping approaches, such as fine-tuning the tempo of the amplitude modulation used to sonify the decreasing distance between the bus and the bus stop. Additionally, efforts will focus on sound design and synthesis techniques to ensure that the sonifications are both pleasant to hear and distinguishable from the surrounding soundscape, such as was the case for the sonification of the door positions. There may also be a need to further explore personalization options for the sonification design (see, for example, discussions on personalization and visual impairments in [51], as well as research on sonification and user-friendliness in [52]), to make it as helpful as possible.

In the qualitative user evaluation, additional possible sonification approaches and support for visually impaired individuals emerged, such as the positioning of scanners for travel passes. Further research is needed to explore suitable sonification designs for these new ideas and how these sonifications can coexist and complement each other. Another important insight from the qualitative evaluation was that the sonification was perceived as most helpful in noisier urban environments. Therefore, future research should investigate whether there is a need to adjust the overall sound level of the sonification in relation to the surrounding soundscape.

One important aspect to further reflect upon is where the sonification should be emitted from. Many regions in ”country” use external announcements for information about bus lines and arrival times, but these can be drowned out by other noises in the environment around a bus stop. Such announcements might also be disturbing for people living nearby and commercial establishments, such as cafes or restaurants. Therefore, as this research project continues, bone-conducting headphones will be explored. These devices allow the user to hear the surrounding soundscape while simultaneously receiving the sonification through the headphones. By using an app on a smartphone, the user can select the bus line they wish to travel with, and the sonification will augment the sound of the bus. However, it is not yet known how the interaction should best be implemented considering sociotechnical aspects [53], and considering the needs of a visually impaired user (see for example discussion in [54]).

The next step in the current research is to further refine the sonification and sound design, and conduct field tests with real buses and blind individuals using bone-conducting headphones, to gain a deeper understanding of how the sonification is experienced.

8. CONCLUSION

This study has found that sonification can be a useful and helpful tool for the visually impaired when traveling with public transportation. Using an increasing *sound level* and *tempo* can successfully represent a decreasing distance between a bus and a bus stop, an upward melodic movement can beneficially function as an *earcon* symbolizing that the bus has arrived, and *pitch* and *rhythm* can be used to represent different positions of doors on a bus. These results are promising, but additional work on the sound design and on the mapping between data and sound parameters is needed. Future research will explore the refined and redesigned sonification in a field study involving real buses and blind individuals in realistic outdoor environments.

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