Supporting Sound Accessibility by Exploring Sound Augmentations in Virtual Reality

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To increase VR sound accessibility for deaf and hard of hearing users, previous work has substituted sounds with visual or haptic feedback. However, many DHH people (e.g., those with partial hearing) can also benefit from modifying audio (e.g., changing volume based on priorities) instead of fully substituting it with another modality. In this demo paper, we present a toolkit that allows modifying sounds in VR to support DHH people. We designed and implemented 18 VR sound modification tools spanning four categories, including prioritizing sounds, modifying sound parameters, providing spatial assistance, and adding additional sounds. We present five demo scenarios with tools incorporated, covering common VR use cases.

CCS CONCEPTS • Human-centered computing~Accessibility~Accessibility technologies

Additional Keywords and Phrases: Accessibility, virtual reality, deaf and hard of hearing, sound, customization.

1 INTRODUCTION

To increase VR sound accessibility for deaf and hard of hearing (DHH) users, previous work has substituted sounds with visual or haptic feedback [14, 21, 25], such as closed captions for in-game dialogs or vibrations to represent enemy footsteps. While promising for some specific sounds, visual and haptic feedback could contribute to information overload [13] and the bandwidth difference with auditory stimuli could hinder accurate information delivery [11, 29].

Moreover, not all DHH users require total sound substitution. Deafness occurs on a spectrum, and DHH individuals have different hearing levels [4, 35]. For users who can hear sounds to some extent, the application can use sound modification techniques like increasing volume or shifting frequencies to audible ranges to deliver sound information seamlessly. Such customization may offer a more intuitive experience than a complete sensory substitution, as indicated by DHH participants in prior evaluations of VR sound substitution systems [14, 22].

In this demo paper, we explore modifying and customizing sounds in VR to better support the needs of users with partial hearing.

2 THE SOUNDMODVR TOOLKIT

We designed 18 sound modification tools that allow users and developers to customize sounds and auditory scenes in a VR app. These tools were informed by prior VR work with DHH users [13, 14, 21], accessibility features in VR games (*e.g.*, Fortnite [2], The Last of Us Part II [39]), accessibility features in modern phones and apps (*e.g.*, live listen feature in iOS), as well as experiences of one of our authors, who identifies as hard of hearing. We divide these tools into four categories based on the sound properties they manipulate.

The *prioritization* tools (PT1-PT4) dynamically adjust the volume of sounds based on developer or user-assigned priority. The *parameter modification* tools (PM1-PM5) adjust loudness, pitch, and persistence characteristics to suit individual users' needs and preferences. The *spatial assistance* tools (SA1-SA5) convey information about the spatial location of sounds and configure how multiple sounds blend in space. The *additional sounds* tools (AS1-AS3) introduce extra sounds into the scene either to convey critical information such as location or to generate an affective state. We explain each tool below.

2.1 Prioritization Tools

Speech Prioritization (PT1): Since DHH people may have difficulty distinguishing speech from background sounds [24, 26, 31], we provide a speech prioritization tool, which can lower the volume of co-occurring environmental sounds during important speech.

Group Prioritization (PT2): During multiple simultaneous groups of conversations, a user might want to focus on sounds from one group. The group prioritization tool reduces the volume of all other surrounding conversations. This tool was inspired by the cocktail-party phenomenon [3], whereby hearing users can switch listening to a "conversation group" based on preference. Besides speech, this feature can also be used to prioritize a group of sounds, for example, sounds emanating from only the leading cars in a virtual car race game.

Keyword Prioritization (PT3): During long speeches, DHH people have requested to be alerted to specific keywords [16] to increase the ease of accessing specific information. This tool allows users or developers to assign keywords to monitor, which, when detected, plays a notification sound. It also restores the volume of the spoken content to its original level if other tools have lowered it.

Direction-Based Prioritization (PT4): Directional amplification of sounds has been known to effectively reduce noise and improve comprehension; it is a common feature in hearing aids [1, 9, 30]. Our tool amplifies the sounds within the 10-degree arc on each side in the direction the user faces while simultaneously reducing the volume of sounds coming from other directions.

2.2 Parameter Modification Tools

System Frequency/Volume Adjustment (PM1): Many DHH users have frequency-specific hearing loss [12, 23, 33]. This tool enables users to shift the frequency range of sounds, as well as adjust the volume system-wide.

Sound Frequency/Volume Adjustment (PM2): Many games allow users to adjust individual sounds or certain groups of sounds [2, 7, 39]. Similarly, this tool enables users to adjust the frequency and volume of individual sound sources.

Frequency Contrast Enhancement (PM3): Since increasing visual contrast has been shown to help low-vision users in VR [36], we propose that increasing the frequency contrast of co-occurring sounds may improve clarity and comprehension for DHH users. This tool adjusts the frequencies of adjacent sound sources, elevating one while lowering the other to enhance their distinction.

Speech Speed Adjustment (PM4): Prior research suggests slowing down speech to improve comprehension for DHH users [34]. This tool allows users to adjust the speed of individual speech sources.

Beat Enhancement (PM5): Inspired by visual and haptic efforts to help DHH users enjoy music [8, 27, 28], we designed a beat enhancement tool that boosts the rhythm of music sounds by dynamically increasing and decreasing the volume along with the beats.

2.3 Spatial Assistance Tools

Left-Right Balance (SA1): To accommodate users with differential hearing in both ears [20], we designed this tool that enables them to adjust the system sound balance to either the left or right, thereby equalizing stereo sounds and amplifying the sound on their preferred side.

Shoulder Localization Helper (SA2): The ability to discern sound direction is crucial for locating spatial sound events–a challenging task for some DHH people [14, 25]. Inspired by VR assistants like Sighted Guide for BLV users [5], this tool provides auditory cues ("To your left" or "To your right") and captions to indicate the direction of important in-game sounds.

Hearing Range Adjustment (SA3): Too many spatial sounds could be undesirable [17]. This tool allows users to adjust the range for sound activation, enabling them to choose desired audio from various spatial sources based on distance.

Sound Distance Assistance (SA4): Auditory distance perception plays a major role in spatial awareness but could be challenging for DHH users [6, 19]. This tool aids in perceiving distance by modulating sound pitch based on the user's proximity to the source: pitch decreases as distance increases and vice versa.

Live Listen Helper (SA5): The iOS Live Listen feature [38, 40] turns an iPhone into a microphone, allowing users to hear better in noisy environments by moving the phone close to the sound source. Similarly, this tool isolates the sound from a source when nearby, muting all others. Users can move it around the scene to isolate the sounds they desire.

Silence Zone (SA6): Developers might overlap the range of multiple ambient sound sources to introduce a transition to a new area, which might lead to sensory overload for users [17]. This tool aims to increase contrast between spatial sounds by including a silence zone between them, facilitating better auditory transitions for DHH users while traversing a VR scene.

2.4 Additional Sounds Tools

Smart Notification (AS1): Games like Fortnite and Persistence [2, 37] use directional icons to provide localized hints for important sound information. This tool enables users to receive a notification sound at the sound source location when important sounds are played.

Custom Feedback Sounds (AS2): Many VR apps include feedback sounds that respond to user actions, but DHH users may struggle to discern these built-in sounds. Inspired by games that support sound customization, like Minecraft [15] and The Sims 4 [41], we developed this tool to offer users a wider range of sound options for specific actions, including variations in pitch, volume, and style.

Calming Noise (AS3): Sound therapy has used calming noises to alleviate tinnitus [10], a symptom connected to deafness [18, 42]. This tool enables users to select among white noise, pink noise, and rain sounds to add to the VR environment.

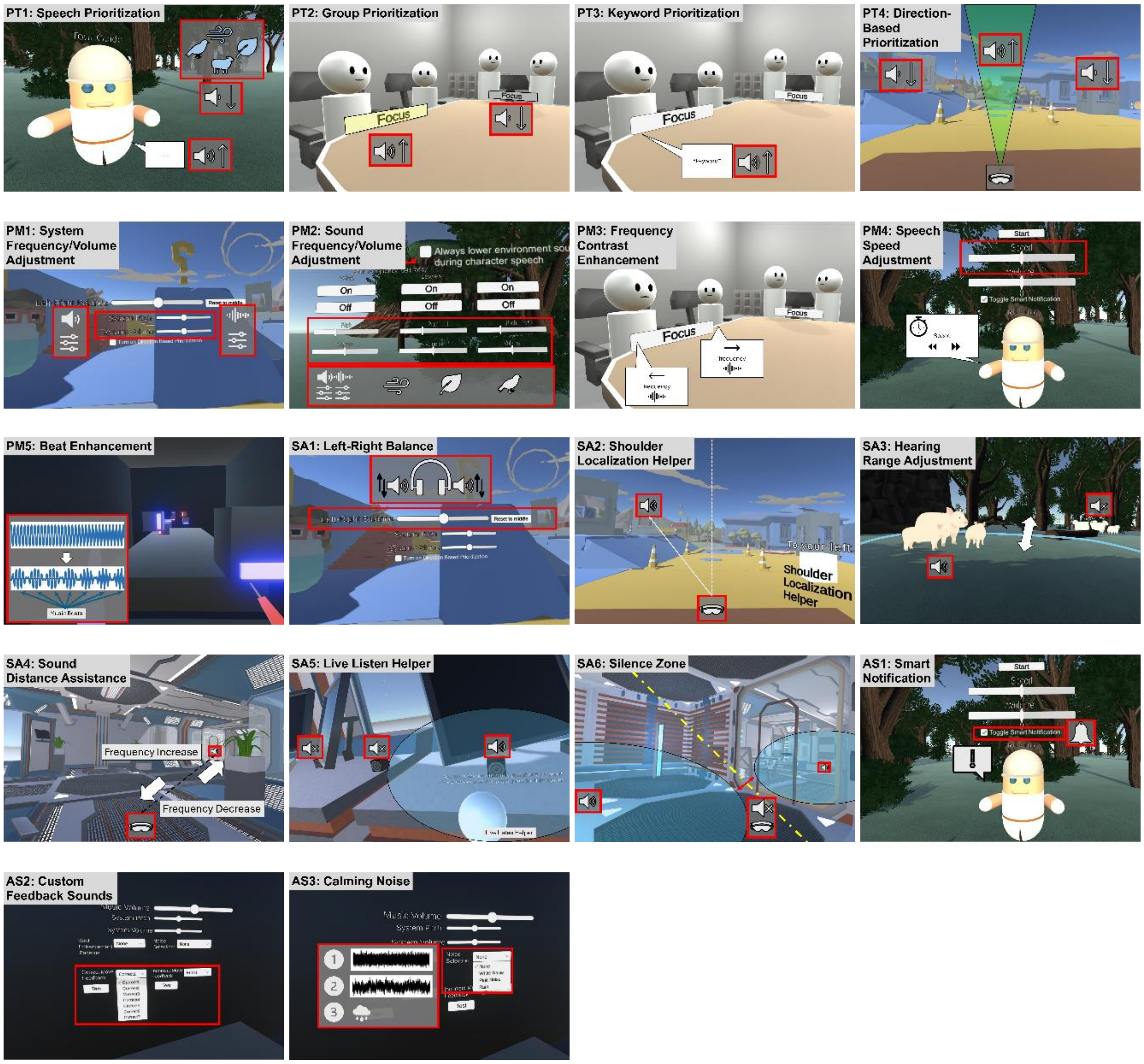

Figure 1: SoundModVR's 18 sound modification tools. These include *prioritization* tools (PT1-PT4), *parameter modification* tools (PM1-PM5), *spatial assistant* tools (SA1-SA6), and *additional sounds* tools (AS1-AS3). The images include the VR screenshots of scenarios used in Study 1 with overlaid graphics (*e.g.*, red boxes, volume icon, callout textbox) to showcase the tool functionalities.

3 DEMO SCENARIOS

During the demo, we will demonstrate our implemented tools on five scenarios we designed that cover common VR use cases (e.g., gaming, nature, educational, music apps):

Scenario 1: Forest Tour. Our first scenario, based in a forest, contains background sounds of wind, leaves, and birds, three groups of animals making localized spatial sounds, and a tour guide providing important information. We implemented six tools in this scenario: (1) PT1 to prioritize tour guide speech over environmental sounds, (2) PM2 to shift the frequency and volume of each environmental sound, (3) PM4 to adjust the speed and volume of the tour guide's speech,

(4) PT4 to prioritize the animal sounds that the user is facing, (5) SA3 to allow users to adjust the range of animals that they hear, and (6) AS1 to play a notification sound when the tour guide speaks.

Scenario 2: Office Convo. This scenario is set in an office with six characters forming three groups of concurrent conversations. We implemented five tools: (1) PT2 to prioritize a certain group of conversations, (2) PM3 to separate two voices close in distance and frequency, (3) PT3 to notify the user when a character mentions a keyword and temporarily increases its volume if lowered, (4) AS3 to add white noise, pink noise, or rain sounds, and (5) SA2 to cue "to your left" for an important sound event originating from the left.

Scenario 3: Shooting Game. This scenario includes enemies shooting the user from various locations, accompanied by movement sounds. We implemented four tools: (1) SA1 to shift all sounds in the game towards the left or right side, (2) PM1 to adjust the volume and frequency of all sounds in the game, (3) PT4 to prioritize the enemy sounds that the user is facing, and (4) SA2 to notify when an enemy starts shooting and whether the enemy is on their left or right.

Scenario 4: Escape Room. This scenario consists of three rooms: a tutorial room, a room where the user finds a speaker playing a sound clue, and a room with a maze leading to an active target sound source. We implemented: (1) SA6 to insert a silence zone between ambient sounds in different rooms, (2) SA5 to let users isolate the clue sound source from other noises, (3) SA4 to change the pitch of the target of the navigation task as the player increases or decreases their distance to the target, and (4) SA2 to inform the user whether the target is on their left or right when they press a button.

Scenario 5: Rhythm Movement. This scenario was inspired from the popular VR game, Beat Saber [32]. Colored cubes move towards the user in sync with music, prompting the user to cut them with the controller. We implemented: (1) PM1 to change the volume and frequency of the music and feedback sounds, (2) PM5 to increase and decrease the music volume in sync with the music beats, (3) AS2 to allow the user to choose the sound notification for correct and incorrect feedback to fit their hearing range, and (4) AS3 to add white noise, pink noise, or rain sound to the ambient scene.

4 LIMITATIONS AND FUTURE WORK

We acknowledge not all DHH people will benefit from enhanced sounds, including people with profound hearing loss and people who are reluctant to use sound information. Nevertheless, based on the diversity of the community [4] and the experience of our hard-of-hearing coauthor, we argue that many DHH users may prefer our approach. Still, future work needs to study our toolkit with the DHH population to validate that they really prefer our approach and implementations.

Moreover, although our VR scenarios covered a wide range of applications, we do not claim that they are exhaustive. Indeed, some VR app genres (*e.g.*, educational and meditation) were not included in our scenario evaluation. We welcome future work to extend the idea of VR sound modification into more diverse scenarios.

5 CONCLUSION

Previous work in VR sound accessibility has covered visual and haptic substitutions of sounds. Our work contributes to the first exploration of sound modification technique to help sound accessibility in VR environments. Some VR games and applications include sound accessibility features, but these are one-off efforts. We offered a more extensible and scalable approach by developing a toolkit that can be integrated into any VR app. Our demo scenarios provide specific VR experiences to showcase the usability of our toolkit.

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