A systematic review of reverberation and accessibility for B/blind users in virtual environments

Luke Child, Dr Natanya Ford, and Dr Thomas Mitchell

University of the West of England

Abstract

Reverberation is often used in linear and non-linear media to convey the acoustic characteristics of a space. This information is presented alongside visual stimuli to create a multi-modal experience, assisting participants in developing visual and auditory maps of a given space. There is a noted relationship between the perception of visual elements of a space in conjunction with the understanding of the same space acoustically by sighted and hearing participants. However, current research also evidences the affordances of reverberation in conveying virtual environment spaces when presented without a visual counterpart. This offers new avenues for accessibility for B/blind people engaging with virtual environments where visual stimuli are inaccessible. This paper presents a systematic review of current research on the use of reverberation in digital and virtual environments and furthermore on its application for B/blind accessibility. The review summarises the affordances of using reverberation in scenarios involving auditory mapping, environment navigation, self, and sound source location, as well as mechanical/gamified uses of reverberation. Furthermore, a brief discussion is given surrounding recommendations for the future of this research area.

Contents

Abstract 2

Introduction 4

2 Review Methodology 6

2.1 Blindness and Language 6

2.2 Research Question 6

2.3 Search Strategy 6

2.4 Research Libraries and Databases 8

3 Data Corpus Analysis 10

3.1 Analysis Overview 10

3.2 Generated Themes 10

3.3 Review Limitations 18

4 Future considerations 19

5 Summary 20

6 Acknowledgements 20

References 21

Introduction

When developing linear and non-linear media experiences, such as television and films, video games or eXtended reality (XR) applications, it is commonplace to design digital or virtual environments to represent real world or newly designed locations. This might range from a digital on-screen representation of a physical location for a film or television, to the creation of virtual game environments for games or XR. There is often a perceptual relationship between the visual and sonic elements of virtual environment spaces, with audio being developed to support a visual counterpart, and vice versa. However, in considering accessibility for B/blind and D/deaf user engagement with virtual environment spaces, a multi-modal experience may include inaccessible information, resulting in the experience not being conveyed successfully. As such, it is crucial to explore both visual and sonic virtual environments in isolation to understand their own individual affordances. In this paper, sound is considered from the perspective of blindness. In a survey from UK Child, Ford, and Mitchell Virtual Environment Reverberation for Blind Accessibility charity Scope, it was found that "66% of gamers with an impairment or condition say they face barriers or issues related to gaming" with the "most used assistive technologies [being] sounds options" [1]. The necessity for this research is conveyed further by the Royal National Institute of Blind People (RNIB) who found that "audio based solutions are most desired by gamers with vision impairments. These include screen reader compatibility, audio description, audio triggers and adaptable audio settings and sound mixes (e.g. spatial audio.)" [2]. In designing virtual environment spaces, the perception of

the acoustic properties of a space can be used to provide sonic information to people, one method of which is through the use of reverberation. The perception of reverberation characteristics has been explored in previous work by the authors [3] and have been evidenced in recent studies to affect parameters such as listener perception of presence [4] and recognising transitions between acoustically different spaces with B/blind participants [5]. Traditionally, research in this area has considered multi-modal experiences often studied with participants who are sighted or who are sighted and then blindfolded/have their vision obscured – however, this does not accurately represent the experience of blindness held by Blind people. Research is beginning to provide inclusive studies that collaborate with B/blind participants, however there is still disparity between studies involving reverberation, and studies involving B/blind participants. This review presents a systematic review of recent research that considers the application of reverberation to virtual environments and its affordances to accessibility with B/blind end users. In comparing research conducted with both sighted and B/blind participants, themes can be generated that suggest areas of overlap in research. The outcomes of the review are presented and discussed to speculate on directions to future research in the use of reverberation in virtual environments for B/blind end users as well as developing inclusive practices in sonic interaction research studies.

2 Review Methodology

2.1 Blindness and Language

This paper uses the phrase 'B/blind' to represent participants with different experiences of blindness. Captialised terminology has been used to represent Disabled communities and identity [6] [7] with lowercase spellings being used for referring to a type of disability [8]. A combination of both approaches is used here to represent community, identity, and blindness. Referring to blindness as an impairment is not used by the author, however the widespread use of the term means its entire exclusion would lead to previous research not being found or considered. Work using the term in this way is thus still included in the review. While this term is used, 'B/blind' is the preferred term in this paper and will be used by the author when referring to B/blind participants.

2.2 Research Question

This review considers the following questions "How has reverberation been used in virtual environments" and "How could/does this facilitate accessibility for B/blind users?".

2.3 Search Strategy

The data corpus collation strategy involves research which employs the use of reverberation in virtual environments with sighted and/or B/blind participants, or references an application to blind accessibility in lieu of participants. A brief overview of the employed search strategy is outlined below:

2.3.1 Search Terms and Phrases

Table 1 outlines examples of search terms used in collating items for the data corpus. All search terms that were used are not included, however those outlined in the table are representative of the style, formatting and phrases used. Items were initially collected in a reference management software and manually assessed via the inclusion exclusion criteria to check their validity, described below:

2.3.1.1 Core search terms and additional queries

Core Search Term	Additional Queries
“Reverberation” OR “Reverb”	accessible/-ility, inclusive/-ity, interaction AND accessible/-ility, interaction AND inclusive-ity, blind OR blindness, visually impaired, visual impairment, virtual environment
“Accessibility” OR “Accessible”	accessible/-ility, inclusive/-ity, interaction AND accessible/-ility, interaction AND inclusive-ity, blind OR blindness, visually impaired, visual impairment, virtual environment
“Blind” OR “Blindness”	Reverb/-eration, interaction AND reverb/-eration, virtual environment

Table 1 - a representative list of utilised search terms.

2.3.2 Inclusion and Exclusion Criteria

The data corpus includes publications that use reverberation in a digital or virtual environment space. The data corpus items include B/blind participants in studies, involve comparisons between B/blind and sighted participants, and/or consider the application of the study for B/blind accessibility. The studies included are available in English. Language bias is acknowledged in this review. English is the native and only language of the author and as such is relied on in data collation due to them being able to only verify research in their native language. This also extends to UK-based societal models of disability. Data items will have been published/made available after December 31st, 2017. It is acknowledged that the proposed date range encompasses the Covid-19 pandemic, reducing the possibility for conducted in-person studies with B/blind participants. The data corpus excludes items that substitute B/blind participants for sighted participants with obscured vision or B/blindness simulation in the review but this work has been considered in parallel to contextualise the authors understanding of current research. Unpublished/grey literature is not used in the review, though some non-academic documentation is used to contextualise information for the review. Publication bias is acknowledged here due to the exclusion of grey literature.

2.4 Research Libraries and Databases

To collate data, research libraries and databases were queried using outlined search terminology. Bibliographic library SCOPUS was used alongside additional manual searches through relevant individual publishing bodies. Queries using the

Title, Abstract and Keywords were conducted initially to find data items with further purposive and snowball sampling being conducted via data item reference lists and additional published works of the discovered authors.

3 Data Corpus Analysis

3.1 Analysis Overview

A hybrid analysis rooted in reflexive thematic analysis [9] was conducted on the data corpus. The author first wrote a brief outline of themselves to understand the perspective that the review was being conducted from. This outline is that the author is a White British, neurodivergent English-speaking Male who is sighted and makes use of accessibility settings in media for assistance in cognitive functions [note taking, slower game speeds, journals/subtitling, for example] and for protanopic colour deficiency. The data corpus was read, analysed and coded using Microsoft Excel to isolate key phrases as codes. After a first pass through, the codes were loosely organised into themes before a second pass of coding was conducted. The codes were finally reduced into the final generated themes presented and analysed in this review.

3.2 Generated Themes

3.2.1 Reverberation is used for the auditory mapping of virtual environments

Reverberation has been shown to enable B/blind participants to develop and employ successful recollection of locations through auditory mapping. In exploring new virtual environments, both solely sonic or with a visual counterpart, research evidences that reverberation aids in the process of remembering spaces while also helping listeners to discern between different spaces and points of interest within a virtual environment. Lopez et al. [5] found in film that, with B/blind participants, "when spatially accurate reverberation is presented to the subject with correct

direct to reverberant levels, subjects found it relatively easy to discern how many positions the character moved to in the scene. This became more difficult when the correct direct to reverberant speech level was presented in mono". They further discuss using spatially accurate atmospheres that are "rendered with accurate reverberation, which consists of a relatively narrow spatial field to reflect the claustrophobic nature of the corridor." To disambiguate environment spaces, they change the reverberation "significantly when the characters move to the kitchen through the right-panned door" to clearly discern the spaces. For game environments, Portillo [10] briefly explores the use of reverberation in audio game case studies that "incorporate real time reverb to indicate a change in the environment". They also note in their own study that "it was noticeable how the participant's matching auditory to memory representation allowed their visual imagery to build an environment that is partially accurate to the one presented in the film". A similar sentiment is expressed by participants in McCarthy et al.'s virtual reality study [11] where the authors note desire for "the ability for users to experience sound changes as they move [through] the changing ambient soundscape, particularly when moving from the reverb rich concourse area to the outside areas." and also within real-time echolocation studies from Andreasan et al. [12], who note that some no-sight-specified participants found reverberation helped them "distinguish the size of [a] room, despite the location (virtual corridor or an opened space)". Reverberation is also suggested to improve spatial mapping alongside other sonic features by Amengual Garí, Calamia and Robinson[13] who hypothesizes that "the high geometrical complexity [of a space], paired with

strong energy from other acoustical phenomena (reverberation level, transmission) would allow users to form spatial mental maps without the need of diffraction". Andrade et al. [14] found that the "use of active echolocation—the use of sounds and echo reverberations over surfaces" in their study "supported the acquisition of mental maps of a virtual space" and that PVI could successfully identify the material a room is made of, the relative size of virtual rooms, and the presence of 90-degree turns for B/blind participants in a virtual environment. Previous research by the authors [3] suggests that, from memory, listeners relied on their physical experiences with reverberant spaces to inform their expectation for these spaces without an aural stimulus. While this study did not consider if participants were sighted or B/blind, it is thought that particular recollection of physical spaces and reverberation might aid the auditory mapping of virtual environments through relying on past experiences with physical spaces. Some research notes the potential difficulty in successfully mapping spaces without a visual counterpart. Piçarra, Rodrigues and Guerreiro [15] quote a B/blind participant's experience in unsuccessfully navigating a hallway. Their participant says "The hallway is long" while walking into a wall, with the authors clarifying a lack of difference between "when walking and colliding for some time, highlighting the difficulties blind participants faced when compared to a sighted person that might easily visually assess the length of the room". It is thought that reverberation in mono/stereo may not be as effective as spatialised sound and reverberation for navigating virtual spaces (explored in the next theme) however it does provide acoustic differences between spaces so that they may be identified easier. In summary, it is

shown that reverberation can aid in developing an auditory map of a virtual location, however this is often in conjunction with other parameters, most commonly with spatialised audio that is being reverberated to act as a reference point. This poses the question of the effectiveness of reverberation in isolation as a method for virtual environment mapping in comparison to its effectiveness in a larger sonic environment.

3.2.2 Reverberation aids in localising the self and sounds in virtual environments

Research has shown different applications of reverberation in aiding in navigation and in localisation of the self and externalised sounds in virtual environment spaces. Rather than providing a characteristic difference between spaces, this theme encompasses being able to identify the location of the self or sound sources from within a virtual environment. Large amounts of research take echolocation into account, however with many publications seeking to use sighted participants whom have obscured vision. Bujacz, Królak and Witek [16] consider reverberation in echolocation in a comparative study between sighted and B/blind participants. The study found that it was "easier to determine the direction of the obstacle than the distance from the obstacle", with "reverberation improv[ing] the echolocation performance as the results obtained in the empty room and outside were much better than in the padded room". Nair et al. [17] also uses echolocation as "a tool that allows players to emit a mouthclick-like sound in all directions and uses the physical properties of the game environment to simulate reverb". Andrade et al. [14] supports this idea, finding that with B/blind participants, "size and materials of rooms and 90-degree turns were detectable through echolocation" through

listening to footsteps as they were most similar to the sound of "clicking sounds with tongue in the real world [that] are really very sharp and very short". However, further study from Nair et al. [18] speculates that participants "could learn to use echolocation, [but] prior work has indicated that it may take weeks for users to learn how to use click-based echolocation effectively". Further research with gamified echolocation might prove beneficial as a method in developing stronger echolocation abilities in the context of a virtual environment within a game, for example. Away from echolocation, there was evidence that reverberation successfully helped participants orient themselves in virtual environment. Andreasen et al. [12] note in their study (no sight level specified for participants) that non-musicians preferred reverberation, as it "helped them to spatially orient better in the virtual environment". Furthermore, navigating through environments with reverberation has also been evidenced. Amengual Garí, Calamia and Robinson [13] developed navigation tasks in VR spaces using acoustic cues including "reverberation by means of bi-directional path tracing". While not working with B/blind participants in their study, they note at 97.33% success rate in listeners navigating to a direct line-of-site position, extending to say "navigation tasks in VR could be leveraged for other applications that require acoustically guided spatial awareness". It is thought that, alongside successfully specialised audio, reverberation could aid in the locating of sound sources within virtual environments by providing listeners more acoustic context for the environments they are present in, alongside accurate spatialisation of sounds within the space in relation to the listener position. Huang et al. [19] explores this with the

successful application of reverberation to enhance depth perception with sighted participants. They note that "Reverb Time influences how users perceive depth and that this influence is more pronounced in the near field" with participants "associating shorter Reverb Times with closer distances (and vice versa)". However, they note further that "overly increasing the Reverb Times (especially in the near field) can lead to sensory segregation wherein the visual information used in perceiving depth does not match with the auditory information, making users unable to perceive the sensory stimuli as one whole unit". It is of interest to consider this further with B/blind participants where visual stimuli may be considered differently.

3.2.3 Reverberation and voice

Research notes the use of reverberation alongside voice to convey space and meaning within virtual environments. The application of inner voice has been explored in virtual reality environments with non-sight-specifying participants by Parkkola et al. [20], though it evidences that "in the case of inner speech, dry non-reverberant speech was deemed the most realistic and entertaining". However, for imaginary characters, the authors confirmed that "voices of the imaginary characters should be rendered in some space, but the space should be easily discernible from the actual room". Lopez, Kearney and Hofstädter [5] notes the use of inner voice and comparisons with traditional audio description to explicitly state spaces within a film. They state their application of enhanced audio description "provides lesser emphasis on the space and focuses on the audience’s understanding of Cecily’s emotions". Importantly, they also note that "even though the EAD version

had sound effects and reverberation cues that may have helped audiences recognise the space, the verbal commentary in AD was something [participants] were more drawn to". The comparison of these outcomes may suggest that reverberation is less desired to the representation of a narrative inner voice and is better applied to external narration or for creative effect as communicating spatial information was preferred to be simple and direct. These findings draw parallels to the I-voice concept presented by Michel Chion [21]. He defines this as a "character's voice separates from the body, and returns as an acousmetre to haunt the past-tense images conjured by its words". He discusses reverberation in this context stating that to convey the I-voice technically, that "the second criterion derives from the first: "dryness" or absence of reverb in the voice (for reverb situates the voice in a space)". He mentions that "it's as if, in order for the I-voice to resonate in us as our own, it can't be inscribed in a concrete identifiable space, it must be its own space unto itself". This is interesting in context to Parkkola et al. [20] and Lopez, Kearney and Hofstädter [5] in that reverberation for personal narrative was deemed to be more successful with a lesser/no reverberation. Further research into successful and unsuccessful scenarios for using reverberation with personal narratives be conducted.
Considering spatialising voice, Portillo[10] considers the aural perspective of the lead character in relation to other elements of audio scenes stating that 60% of B/blind participants expressed how, in correlation with audio description, "[character aural perspective] helped them to empathise with the main character and to have a better understanding of the distance, direction and position of the visual elements from an amplified

auditory experience". In considering the position of the listener, "it allowed volunteers to have a more detailed and immersive storytelling experience". It is thought that, in conjunction with the aforementioned uses of reverberation, immersive storytelling could be enhanced further through selective use of reverberated and non-reverberated voice for present and imaginary characters alongside spatialisation of sounds within the scene. In terms of B/blind accessibility, this may afford for narrative to be conveyed through less explicit verbal descriptions of scenes and characters, instead to be conveyed through reverberation and spatialised audio.

3.2.4 Reverberation can be used as a game mechanic

It is proposed that many of the considered applications of reverberation in this review could be used to provide a gamified function within an interactive environment. Wedoff et al. [22] notes the successful use of reverberation (alongside other audio processing such as specialisation, and other game mechanics) to aid in localising a ball in a virtual reality game with B/blind participants. The sound implemented in this study featured a combination of simple reverberation, spatialisation, and other audio processing to covey the position of a ball in a virtual reality game environment. Similarly, Nair et al. [18] uses an audio shockwave mechanic to provide players with information about their virtual environment space, including room characteristics and items within the space. This implementation utilised echolocation alongside an item filtering option that informed players about "all objects, mission critical points-of-interest, non-mission-critical (decorative) objects, [or] walls only". This was alongside a directional scanner that announces

a 3D sound from the point of the object in line of site in space. While not an explicit tool in its own right, reverberation alongside additional specialisation has been used successfully to create gamified audio mechanics that provide an alternate method of interaction while also sonically informing the user about a virtual environment.

3.3 Review Limitations

A primary limitation of this study is the difficulty in standardising terminology in terms of reverberation, virtual environments, and the B/blind experience. As for the B/blind experience, developments in terminology across research disciplines presents a difficulty in isolating research when designing initial criteria and conducting systematic searching. A single phrase or term is often used consistently throughout pieces of research, however. In the UK for example, the RNIB outline the use of the terms 'Blind' or 'Partially Sighted' or to have 'Sight Loss', moving away from the use of 'Impairment' [23] however, many accessed pieces of disability research often refer to impairment. It is desired that moving towards inclusive language in audio research is crucial to allow firstly for better indexing, however more importantly for inclusivity in audio accessibility research. Ultimately, it is important to consider the approach outlined the RNIB that "it should always be a disabled person's needs that dictate whether a medical or social approach to their disability is most relevant at any particular time" [23]. The date range considered here also includes the Covid19 pandemic which posed a limit on in-person studies being conducted. There is a possibility that given social bubbles and reduced travelling, access to B/blind participants for studies may have been limited, which may reduce the number

of relevant studies conducted, or may have been motivation for using convenience sampled sighted participants with obscured vision to comply with restriction guidelines in lieu of externally sourced B/blind participants.

4 Future Considerations

In conducting this review, it is concluded that reverberation has the potential be used successfully with B/blind participants to provide accessibility to experiences using digital and virtual environments. The presented data corpus of secondary data shows successful practices in developing research studies around reverberation with B/blind participants or evidencing the need for further studies into accessibility given their results. In forming the data corpus, it was found that many studies not included in the review studied in virtual spaces but did not include the use of B/blind participants. Furthermore, many studies hypothesised that their results would be beneficial to B/blind participants. New research should consider diversifying their participant pools or conducting additional studies to include B/blind participants to further the understanding of audio research in regards to blindness and accessibility. It was found on many occasions that audio research aimed towards blindness and accessibility was conducted without B/blind participants, instead electing to use sighted participants with obscured vision. Furthermore, in certain literature, terminology such as 'normally sighted' or 'suffering with blindness' was used. It is crucial to reflect on the available research working towards successful inclusive research practice and to employ this across audio research.

5 Summary

This paper provides a systematic review of current literature pertaining to the application of reverberation in virtual environment spaces and the affordances this could provide to B/blind participants and accessibility. A data corpus was collated using published data items governed by inclusion and exclusion criteria. This data corpus was analysed using reflexive thematic analysis to generate themes in relation to extracted codes from each data item. The review evidences the affordances of using reverberation in scenarios involving auditory mapping, environment navigation, self and sound source location, and mechanical/gamified uses of reverberation. Furthermore, considerations for future research are presented alongside acknowledgements towards the need for research conducted with sighted participants to consider additional studies with B/blind participants to create more unified outcomes with regards to blindness and accessibility.

6 Acknowledgements

This research paper was completed as part of a funded PhD at the University of the West of England, Bristol.

References

1. Accessibility in Gaming Report, Scope, 2021, https://www.scope.org.uk/campaigns/research-policy/accessibility-in-gaming/

2. Accessible Gaming Research Report, Royal National Institute of Blind People, 2022, https://media.rnib.org.uk/documents/RNIB_Accessible_Gaming_Report_2022.pdf

3. Child, L. and Ford, N., “Towards an audio attribute framework for understanding the perception of reverberant spaces through elicitation and clustering methods based on participant expectation,” in Audio Engineering Society Convention 150, 2021.

4. Kelly, J., Woszczyk, W., and King, R., “Are you there?: A Literature Review of Presence for Immersive Music Reproduction,” in Audio Engineering Society Convention 149, 2020.

5. Lopez, M., Kearney, G., and Hofstädter, K., “Seeing films through sound: Sound design, spatial audio, and accessibility for visually impaired audiences,” British Journal of Visual Impairment, 40(2), pp. 117–144, 2022, ISSN 0264-6196, doi: 10.1177/0264619620935935.

6. Disability Language Style Guide, National Center on Disability and Journalism, 2021, https://ncdj.org/

7. Sticks and Stones: The Language of Disability, SPECTRUM Centre for Independent Living, 2018, https://spectrumcil.co.uk/.

8. Inclusive language: words to use and avoid when writing about disability, Cabinet Office Disability Unit, 2021, https://www.gov.uk/government/publications/inclusive-communication/

9. Braun, V. and Clark, V., Thematic Analysis: A Practical Guide, Sage, 2022, ISBN 9781473953239.

10. Portillo, C., “Films Unseen: Approaching Audio Description Alternatives to Enhance Perception,” in Audio Engineering Society Convention 144, 2018.

11. McCarthy, C., Lai, T. D., Favilla, S., and Sly, D., “Towards an Immersive Auditory-based Journey Planner for the Visually Impaired,” in Proceedings of the 31st Australian Conference on Human Computer Interaction, pp. 387–391, ACM, Fremantle WA Australia, 2019, ISBN 978-1-45037696-9, doi:10.1145/3369457.3369499.

12. Andreasen, A., Zovnercuka, J., Konovalovs, K., Geronazzo, M., Paisa, R., and Serafin, S., “Navigate as a bat. Real-time echolocation system in virtual reality,” in Proceedings of the 15th Sound and Music Computing Conference: Sonic Crossings, SMC 2018, pp. 192–199, 2018, ISBN 9789963-697-30-4.

13. Amengual Garí, S. V., Calamia, P., and Robinson, P., “Navigation of virtual mazes using acoustic cues,” in Audio Engineering Society Convention 154, 2023.

14. Andrade, R., Waycott, J., Baker, S., and Vetere, F., “Echolocation as a Means for People with Visual Impairment (PVI) to Acquire Spatial Knowledge of Virtual Space,” ACM Transactions on Accessible Computing, 14(1), pp. 1–25, 2021, ISSN 1936-7228, 1936-7236, doi:10.1145/3448273.

15. Piçarra, M., Rodrigues, A., and Guerreiro, J., “Evaluating Accessible Navigation for Blind People in Virtual Environments,” in Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems, CHI EA ’23, pp. 1–7, Association for Computing Machinery, New York, NY, USA, 2023, ISBN 978-1-4503-9422-2, doi:10.1145/3544549.3585813.

16. Bujacz, M., Królak, A., Górski, G., Matysik, K., and Witek, P., “Echovis – A collection of human echolocation tests performed by blind and sighted individuals: A pilot study,” British Journal of Visual Impairment, 2022, ISSN 0264-6196, doi: 10.1177/02646196221116728.

17. Nair, V., Ma, S.-e., Huddleston, H., Lin, K., Hayes, M., Donnelly, M., Gonzalez, R. E., He, Y., and Smith, B. A., “Towards a Generalized Acoustic Minimap for Visually Impaired Gamers,” in Adjunct Proceedings of the 34th Annual ACM Symposium on User Interface Software and

Technology, pp. 89–91, ACM, Virtual Event USA, 2021, ISBN 978-1-4503-8655-5, doi:10.1145/ 3474349.3480177.

18. Nair, V., Ma, S.-e., Gonzalez Penuela, R. E., He, Y., Lin, K., Hayes, M., Huddleston, H., Donnelly, M., and Smith, B. A., “Uncovering Visually Impaired Gamers’ Preferences for Spatial Awareness Tools Within Video Games,” in The 24th International ACM SIGACCESS Conference on Computers and Accessibility, pp. 1–16, ACM, Athens Greece, 2022, ISBN 978-1-4503-9258-7, doi:10.1145/3517428.3544802.

19. Huang, Y.-H., Venkatakrishnan, R., Venkatakrishnan, R., Babu, S. V., and Lin, W.-C., “Using Audio Reverberation to Compensate Distance Compression in Virtual Reality,” in ACM Symposium on Applied Perception 2021, pp. 1–10, ACM, Virtual Event France, 2021, ISBN 978-1-4503-86630, doi:10.1145/3474451.3476236.

20. Parkkola, K., McKenzie, T., Häkkinen, J., and Pulkki, V., “Representing Inner Voices in Virtual Reality Environments,” in Audio Engineering Society Convention 154, 2023.

21. Chion, M., The Voice in Cinema, Columbia University Press, 1999, ISBN 978-0-231-10823-2, pages: 208 Pages.

22. Wedoff, R., Ball, L., Wang, A., Khoo, Y. X., Lieberman, L., and Rector, K., “Virtual Showdown: An Accessible Virtual Reality Game with Scaffolds for Youth with Visual Impairments,” in Proceedings of the 2019 CHI Conference

on Human Factors in Computing Systems, pp. 1–15, ACM, Glasgow Scotland UK, 2019, ISBN 978-14503-5970-2, doi:10.1145/3290605.3300371.

23. Understanding Sight Loss: Flexible learning for staff and volunteers, Royal National Institute of Blind People, 2017, https://rnib.org.uk/