Utilising Elicitation Methods to Understand and Design Informative and Accessible Experiences of Digital Reverberation

Luke Child

Supervised by Dr Natanya Ford

Written as a part of an MSc in Creative Technologies

University of the West of England

November 2020

Word count: 13722

Abstract

Reverberation is a phenomena that brings life and character to sound experienced in physical space, providing a listener with understanding on their location and the space around them. However, for those with accessibility concerns, such as sight or hearing loss, this usually aural experience cannot be fully understood. As such, it is desirable to enhance the current applications of reverberation in digital experiences so that both able and non-able participants can fully engage with the medium. This project utilises elicitation practices to analyse how reverberation is engaged with and understood from memory and with the presence of aural stimuli. Preliminary results show that the reverberation in various physical locations is described with a focus on differing specific features relevant to that space, and that participants often describe reverberation using emotive and descriptive adjective-oriented terminology. Further investigation is proposed through additional participants and RepGrid use to reinforce these findings. The results suggest that describing locations based on their reverberation characteristics and the emotive and adjective-oriented terminology could be an effective tool in enhancing the presence and overall experience in future digital media involving audio and reverberation for both able and lesser-abled listeners alike.

Tags

Reverberation, elicitation, accessibility

Table of Contents

Abstract 2
Acknowledgements 5
Introduction 6
  Research Aims and Objectives 8
Review of Literature 9
  Sound Perception 9
    Localisation 9
    Perception and Reverberation 10
  Sound and Experience 11
    Sound and Experience in Games 11
    Sound and Reverberation as Experience 13
  Audio and Accessibility 14
    Accessibility and Media 14
    Accessibility and Audio Perception 15
  Literature Summary 15
Methodology 17
  Literature 17
    Elicitation and the Individual 17
    Elicitation and Audio 18
  Precognitive Understanding of the Reverberation in Physical Spaces 20
    Survey Data 20
    Survey Design 20
  Triadic Elicitation with Digitally Reverberated Audio Samples 23
    Study Design 23
    Survey Respondents 24
    Design Evaluation 24
Results 26
  Study One – Precognition Survey 26
    Approaches to Data Analysis 26
    Considerations for Biased Data Analysis 26
    Distribution of Language 27
    Location Analysis 28
    Study One Summary 41
  Study Two – Triadic Elicitation Pilot Study 42
Conclusion 46

Project Conclusions 46
References 47
Appendix 50
Reverberation from Memory Study raw results 50
Triadic Elicitation Pilot Study raw results 50

Table of Figures

Figure 1 - Question template for participants 23
Figure 2 - Pie chart showing language type distribution 27
Figure 3 - An example RepGrid based on participant results 45

Table of Tables

Table 1 - Breakdown of study participants 21
Table 2 - Weightings for language types discussed 28
Table 3 – Triadic elicitation results table based on participant results in pilot study 42
Table 4 - Elicitation poles table generated based on Francombe Et Al (2017) 44

Acknowledgements

First and foremost, I would like to give a massive thank you to Dr Natanya Ford for her supervision on my project. Her knowledge, generosity and kindness have been second to none and I am immensely grateful to have worked alongside her throughout the course of this dissertation. I would like to give thanks to my partner, Paige for her incessant support and courage alongside me while she writes her own dissertation and makes me incredibly proud while doing so. Final thanks are given to Alexandre Hurr for his endless care and selflessness in looking out for me and providing copious amounts of wine and music while I almost certainly should have been writing.

Introduction

When a listener is present in a space, the sounds they hear are filtered by features and contents of the space. This is known as reverberation, a phenomena that, through a series of reflections and filtering, allows the human listener to discern various information about the space they are in. The development of modern media formats allows many viewers and listeners to partake in and engage with a plethora of spaces and environments digitally, such as in film, video games and virtual reality experiences. With this comes the use of digital reverberation that mimics the reverberation one may find in a parallel physical location, achieved through careful parameter matching or convolution reverberation via impulse responses. The role of reverberation in both physical and digital experience is multifaceted, providing information on the position of the self in relation to other items, as well as being a key indicator for the size and space of the present location. An additional purpose for digital reverberation though comes in the experience of 'presence', more so how the characteristics of a room's reverberation may affect a listeners feeling of 'presence' in a space. Brown and Cairns speak of presence in games as the feeling of "being cut off from reality and detachment to such an extent that the game was all that mattered" (Brown and Cairns, 2004). Digital reverberation can be viewed as a perceptual 'atmosphere' here, by providing a true sense of space to sounds that would occur within its parallel physical format. If a listener is in a large reflective room, for instance, it would seem counterintuitive to them to have sounds that felt dull and decayed quickly. The reverberation and atmosphere should, as Jorgensen outlines regarding sound and virtual environments, foster an "atmospheric function" to create an "atmospheric symbiosis" that is believable to a game player (Jørgensen, 2009). The concept of "perceptual fidelity" in terms of reverberation would also suggest that, provided the reverberation was "lifelike and naturalistic" (Jørgensen, 2009) to the perceptions of the player, then a successful virtual environment can be created and thus can begin to foster higher levels of presence in the player. But what are the expectations on reverberation amongst human listeners? Evidence suggests this, stating that our understanding of reverberation in "modern industrialized society" has a partially shared experience of reverberation perception across listeners. (Traer and McDermott, 2017) Reverberation provides a sense of presence to a listener not only through solidifying one's understanding of positioning and orientation, however also a perceived fidelity from the listener towards how sound should react to the content of the environment based on their own experience. Hindering though, is a barrier in engagement to such content by viewers with accessibility challenges such as sight and hearing loss. With a lessened sense of hearing, listeners would find it difficult or impossible to understand and interpret perceptual cues from

reverberation, leading to a lack of contextualised sounds or sound descriptions. Similarly, those with a lessened sense of sight or blindness will rely heavily on audio cues to understand sound and reverberation, though without complimentary visual stimuli, may have difficulty understanding the context of sound when no visual context is present. While alternative access options are in place, such as the inclusion of Audio Descriptive (AD) television, audio subtitling and sign-along media, these options provide a diminished experience, offering a compromise rather than an alternative to the original media.

This dissertation seeks to showcase how able listeners of sound interact with and decode reverberation, both from a precognitive and aural context. Methods will be suggested for developing better implementations of reverberation in digital media to create more informative and engaging audio experiences. A review of literature will be completed to isolate current research in the perception of audio and spatial audio, the way audio is understood differently by abled and lesser-abled listeners, and how we can elicit information from participants in audio-focused research to better understand how audio is engaged with. Reinforced by the literature, an approach will be discerned by evaluating appropriate methods in elicitation to design studies for eliciting information on reverberation. Studies will then be undertaken to gather information on how digital reverberation is understood both from memory and with aural stimuli present. This could lead towards better methods of describing reverberation for those with hearing loss, and also provide key information to inherent sonic components for those with sight loss.

Research Aims and Objectives

The aim of this research is to provide an initial engagement in eliciting experience-related information on reverberation to design improved experiences of reverberation in digital media.

The key research questions are:

- How do people approach describing reverberation without visual or aural stimuli?
- Are language trends apparent when analysing precognitive descriptions of location-based reverberation?
- How does this this reflect through aural testing?
- How can this data be used in designing better experiences with reverberation?

The primary goals are:

- Design and critique study approaches when querying precognitive descriptions of reverberation in physical locations
- Identify descriptive factors and trends in participants when discussing reverberation from memory
- Propose guidelines for describing location-based reverberation
- Develop initial studies into audio-focused elicitation studies for wider distribution

This motivation and significance for this research comes from a need for better descriptions and implementations of audio, specifically reverberation, in digital media experiences being consumed by those with accessibility concerns. Current research in this area includes work such as the Enhancing Audio Description project (Lopez and Kearney, 2016), the Game Accessibility Guidelines (2012), a series of accessibility reading for better game design for accessible players, and work on creative audio description (Walczak and Fryer, 2017) and immersion in audio description (Walczak, 2017) . This research will focus specifically on understanding and describing reverberation and how it can be represented more accessibly in digital media experiences.

Review of Literature

Sound Perception

When sound disperses throughout physical space, the space's physical build-up interacts with it, providing a plethora of filters and colourations that affect how a listener perceives them. Surfaces may scatter or reflect sound, create reflections that are dullened or brightened by a materials properties or may get lost into the length of a large space, while instead providing a sense of intimacy in smaller locations. These physical properties such as material and density, size and shape give physical space a personality. This 'room personality' is more commonly known as reverberation; the resultant perception of a physical space's characteristics through the listening and decoding of various reflections of sound in the given space. Reverberation provides a listener with a sense of space and presence in a location, allowing them to decipher their orientation in relation to other stimuli and also understand the physicality of the space.

Localisation

The reason human listeners can understand such information from reverberation is due to binaural hearing. The binaural nature of hearing throughout various species of animals means that there are two points of reference to receive and interpret sound from. The geometry of human ears provides such binaural hearing functionality; the placing of two listening points (the ears) separated by the physical space between them (the head). Due to this spacing, differences in sonic parameters occur at each ear and are recognised and processes by the brain. These differences are known as interaural differences, with the two most common being recognised as interaural time difference (ITD) and interaural level difference (ILD). Respectively, these are the dissimilarities in phase and perceived sound pressure level on arrival to each ear. The most prominent and recognisable factor is the difference in arrival time between direct, unfiltered sound waves compared to reflected, indirect sound waves (Schnupp, Nelken and King, 2011). Sound waves propagating from a single source, given a direct, unobstructed line of sight to each ear, will reach the listener in an unfiltered state. This provides the listener with a sense of direction given the ITD and ITD between each ear. Given no obstacles or walls to alter the sounds path, the sound level will decline with the inverse square of the distance travelled; around 6dB per doubling of distance. This decline of level suggests distance to a listener, with the lower the amplitude the sound suggesting a further distance for the sound to have travelled. However, this scenario, given the various locations experienced by a person, is unlikely to be experienced naturally. It is interesting to note here that precognitive knowledge of the sound source affects the perception of distance. Prerequisite information

about the sound, such as its intensity and the physical size of the source affect the reliability in accurately depicting the distance of a sound from the listener. As such, perception of distance with human conversation or voice as a stimuli are more precisely gauged than that of a sound source that is unfamiliar to the listener in terms of intensity and size. (Schnupp, Nelken and King, 2011). Similarly, sounds existing in near field absolute locations are also more accurately perceived.

Perception and Reverberation

Reverberation crucially however is not a source of sound, moreso a post-sound filtering provided by the environment. Traer and McDermott found that the brains of human listeners have "internalized the regularities of natural reverberation", with their results suggesting that "although there has been little direct evidence for separation of source and filter in reverberation perception, several previous findings are consistent with a separation process" (Traer and McDermott, 2016). This is suggestive that, while reverberation does not provide sound per se, the qualities inherent to it are noticeable enough so that the listener can separate the source from the filtering. The research goes on to discuss this, posing that "the reverberation encountered by humans in modern industrialized society is probably not qualitatively different from what was typical in preindustrial societies" and that "[the] results leave open the question of whether knowledge of natural IR regularities is present from birth or learned over development" (Traer and McDermott, 2016). This result speaks in favour of reverberation in particular locations, especially those pertaining to "modern industrialized" locations, being an experience that could be commonly understood. If this was to be the case, then reverberation could be utilised universally to enhance or detriment experiences based on the fidelity of accuracy in the reverberation provided for a given location.

Sound and Experience

While it is discerned that sound provides a listener with information on orientation and localisation, and as such in a digital context like a game for instance, provides functionality through sound to a player. Spatialised sound can alert a player to a threat being to their side through exploiting the stereo image, or to the direction and distance of an objective through long reverberation. However, furthering this is the idea of using sound for immersive purpose, and how informed sound design may lead to higher levels of immersion in digital media experiences. Immersion and flow have a deep history with research with Csikszentmihalyi and *Flow: The Psychology of Optimal Experience,* though in the context of this dissertation, the immersive properties of sound will be analysed through more recent research approaches such as Jørgensen's ideas on fidelity, presence and atmospheric function (Jørgensen, 2009) and Brown and Cairns approaches of presence and total immersion (Brown and Cairns, 2004).

Sound and Experience in Games

With regards to audio, the conscious and subconscious usage of aural cues is pertinent to many complete experiences of a game. Reverberation, while not a source of sound, has a prominent effect on sound, and as such needs to be considered both in its purpose and its diegetic position. It is first important to classify where reverberation fits in terms of how it is experienced. Kristine Jørgensen proposes four primary functions for sound in games: usability, orienting, atmospheric, and identifying. As discussed, reverberation exists to provide a listener with a sense of orientation and information as to the characteristics of the room, satisfying the function of Jorgensen's orientation, which seeks to be concerned with "information about the existence, presence, and relative location and distance of objects events and situations in the game environment" (Jørgensen, p158. 2009). The area that becomes interesting is analysing reverberation under the category of atmosphere and the idea of presence. Brown and Cairns discuss levels of immersion in games and propose three levels of immersion in games, engagement, engrossment and total immersion (Brown and Cairns, 2004). These three levels outline stages of immersion in a games content and focus on the requirements needed by a gamified interactive experience to allow a player to reach each level of immersion. Engagement primarily concerns itself with the initial barriers for experiencing a game: *do I like the genre of game? Do I need to invest lots of time? Does it hold my attention long enough to do so?* When these are met, players can begin to experience engrossment. This is when "game features combine in such a way that the gamers' emotions are directly affected by the game" (Brown and Cairns, 2004). Brown and Cairns note that participants in their study noted "visuals", "interesting tasks"

and “plot” as factors at this level. The general census here is that engrossment is when the effort put into design and implementation is notable; the basic levels of engagement are met, and now emotional investment can take place in the construct of the game and its constituent parts. Total immersion is the final stage of immersion in this study and is concerned with the detachment of the self from one’s own reality into the reality of the game world. This stage is perhaps synonymous here with the idea of ‘presence’. Noted in the study is that “participants described being cut off from reality and detachment to such an extent that the game was all that mattered” (Brown and Cairns, 2004). Suggested here is the notion that “the barriers to presence are empathy and atmosphere”. The correlation here between the idea of atmosphere, mood and presence becomes present when reverb is brought into focus.

Alternative frameworks can also be used to understand the function of reverberation, such as the IEZA system (Van Tol and Huiberts, 2008). This framework consists of two axes: Diegetic to Non-Diegetic and Setting to Activity. Diegesis in this context is the origin and function of a sound source, taking from Stockburger approach (2003) and also from Jørgensen’s definitions towards diegesis. While reverberation is not considered a source of sound, it does provide noticeable changes to audio with characteristics intrinsic to itself and as such it is deemed here that reverberation can be analysed through these scopes. Reverberation as discussed here provides orienting and atmospheric functionality. In a video game context, it serves both the purpose of informing a player themselves and things in their environment, perhaps alerting them to a threat from behind and also how far away that is. This function is non-diegetic and orienting, or in IEZA terms Affect, seeking to provide information to the player to allow them to succeed in the game. The reverberation, while intrinsic to a diegetic part of the game (the local environment) seeks to communicate with the player to aid them. However, it also provides an atmospheric function, or in IEZA terms, the zone, a diegetic function. It provides the user with a reverberation on played sounds that is appropriate with the local environment, assisting in fostering a sense of presence while playing. In Jørgensen’s terms, this could be consider a form of ‘internal transdiegetic sound’, a function of sound that occurs from within the diegesis of the game environment, but with purpose that directs the agency of the player externally (Jørgensen, p109. 2009). With this understanding of reverberation having a transdiegetic function, it seems feasible that, should reverberation elicit further responses from a listener such as an emotional response, that it could be crafted in such a way as to influence this elicitation.

Sound and Reverberation as Experience

In order to use reverberation to control alternative aspects of experience, it is crucial to understand the experiences it could influence. Mo, Wu and Horner found evidence of this in how reverberation affected the emotional perception of music, showcasing a "significant effect on Mysterious and Romantic for the back of a large hall; a medium effect on Sad, Scary, and Heroic for the back of a large hall; a mild effect on Happy for the front of a small hall; relatively little effect on Shy; and the opposite effect on Comic, with listeners judging anechoic sounds most Comic"(Mo, Wu and Horner. 2016). Further research by Paterson et al (2010) suggests the importance of reverberation in immersion in a video game context with "the majority of testers (67%) found the reverberated samples more emotionally engaging with 77% also perceiving these samples to be more immersive when compared to the dry audio samples."

Discussions around the experience of audio experience and sentimentally are an interesting addition to the literature. Duel et al studied into the design of audiography, a concept based on the idea that it is "commonplace to capture and share images in photography as triggers for memory. In this paper we explore the possibility of using sound in the same sort of way, in a practice we call audiography" (Duel, Frohlich, Kroos and Xu, 2018). Literature often explores how audio is affective in a given moment, however this study considers a precognitive or memorable approach to audio, using it is a stimuli for experience recollection. Other research acknowledges the role audio as a recollective tool, with Oleksik and Brown stating "by mining the audio memory, we uncovered sets of sounds which participants remembered warmly and wished to hear again" (Oleksik and Brown, 2018). Dib, Petrelli and Whittaker reinforce this, and found that "a huge range of different sounds can serve as mementos, and the reason for constructing a given memento is private and highly symbolic" (Dib, Petrelli and Whittaker, 2010). Though reverberation is not directly a cause of sound, it is a form of sound filtering that is implicit to a given location which, considering the similarities in sets of locations, could provide a more universal set of thoughts and feelings when used to filter and reverberate audio samples.

Audio and Accessibility

While it seems fair to assume that physics affects the self in a universal fashion, the tools at one's disposal to interpret sound do alter the experience provided. Though sensical functionality such as sight and hearing exist similarly between humans with minor individual deviation, many individuals may have reduced or lost functionality of certain senses, such as the manifestation of blindness or deafness across the seeing or hearing spectrum. Given the impact of sound design, reverberation and presence discussed prior, this would suggest that those with accessibility concerns will receive a detrimental experience when accessing media utilising current sound experiences. This section acknowledges the importance and state of accessible users of digital media formats and begins to understand the ways perception of sound may differ and how this could be considered in future sound experiences.

Accessibility and Media

Action on Hearing Loss (2018) estimated that "In the UK there are 12 million adults with hearing loss greater than 25 dBHL" and the Consortium for Research in Deaf Education reported that "there are at least 53,954 deaf children across the UK" at varying levels of deafness. Furthermore, the National Health Service reports that "in the UK, there are almost 2 million people living with sight loss. Of these, around 360,000 are registered as blind or partially sighted" (NHS, 2020), which expands further in data sets from the World Health Organisation suggesting that "globally, at least 1 billion people have a near or distance vision impairment that could have been prevented or has yet to be addressed" (WHO, 2020). When considering digital media in the modern era, video games are a significant medium. A 2020 study by Newzoo found that "2.7 billion people globally play video games across any device type, growing +6.4% from the previous year" (Newzoo, 2020). This said, in the USA alone, of the circa 215 million players in the USA, 46 million of those identify as having an experience-impairing disability (ESA 2020). More holistically, a survey by the Information Solutions Group (on behalf of PopCap Games) found "more than one in five (20.5%) players of casual video games have a physical, mental or developmental disability" (2008). Game developers and hardware manufacturers are aware of this, however much of the research in this area focuses on creating accessible versions of games albeit with reduced functionality. While this efforts create pathways into accessing the core experience of games, they do not offer the same level of access to that of an able gamer. Generally, the adaptations of modern media, though improving, do not provide sufficient, holistic support for those affected by sight and hearing loss. The Royal National Institute of Blindness reported that "most major broadcasters (like the

BBC, Channel 4 and Sky) provide AD on 20 per cent of their programmes", with Ofcom noting the lack of accessible audio and visual options also, stating that "catch-up and on-demand services are increasingly popular, but these services are often not accessible to people with hearing and sight impairments, because they don't provide features like subtitles, audio description and signing" (Ofcom, 2020).

Accessibility and Audio Perception

While accessibility is a concern for many, it seems fitting that experiences cater to, support and if possible, improve any additional needs an individual may have. The perception and experience of audio by those with vision or hearing loss has been the topic for various research and outlines the necessity for accessible audio experiences in digital media. Lahav and Mioduser (2004) utilised audio feedback for orientation and interfacing with a blind user during virtual environment research They manipulated sound design and echoing, stating that "during navigation, the provision of footstep sounds and echoes increases not only the reality to the blind user, but also the sense of actual scale". The results of this study included "the exploration of the real space contributed to the control group's ability to estimate the objects' size and distances among them" through the use of physical and audio-based stimuli. Lopez also utilised reverberation, stating it was "used throughout the audio film in the form of reverberation to differentiate the different spaces in which the characters interact as well as to indicate [a character's] thoughts" (Lopez, 2015). She notes that "in some cases it became evident that listeners were using their own experience of similar spaces to provide descriptions, meaning the reconstruction was not necessarily based on what they listened to but what they expected the space to be like" (Lopez, 2015).

Literature Summary

The binaural perception of sound provides the listener with information about their orientation in the context of space, as well as the space itself. The collective filtering that the space provides to afford this information to the user is reverberation. Listeners are thought to have an innate ability to separate sounds in an environment from the reverberation the environment provides, meaning that the characteristics of the reverberation can be understood independently and thus experienced independently. Since reverberation is not explicitly a source of sound however, it is difficult to understand its position in experience in the context of digital media. It is thought that sound falls under the category of presence, the feeling of 'being' in a virtual space. The accuracy of reverberation based on the previous experience of the listener helps to foster a more involved sense of presence. This may lead some audio designers to utilise this property of

reverberation as a presence-enhancing tool in digital media experiences. However, this becomes a challenge when designing experiences for experience participants with accessibility concerns, specifically with vision or hearing loss. Research into audio experience for the visually or aurally impaired shows the benefit of utilising reverberation and improved audio descriptions on the accuracy of understanding in digital experiences. It is thought reverberation could be utilised further to not only provide high perceptual fidelity for sound design in accessible media, but also provide heightened and controlled senses of presence and emotive responses for able and non-able experiencers alike.

Methodology

Literature

The core literature in this study revolves around how sound and reverberation are understood and the effect they can have on a listener from a general context. However, the studies in this project focus on the individual experience in a qualitative format, and as such provide less initial quantifiable information to analyse. The difficulty here is firstly eliciting and understanding the responses of the individual, but also contextualising those responses impartially as a whole.

Elicitation and the Individual

Elicitation techniques can be defined as "a category of research tasks that use visual, verbal, or written stimuli to encourage participants to talk about their ideas" (Keith Barton) and are useful in the discussion of topics that relate to the experience and opinion of the individual. Psychologist George Kelly begins this discussion with Personal Construct Theory, a theory in which experience pertains to the individual and their own series of personal constructs that allow them to "structure and anticipate the themes of their lives" (Neimeyer, 2009) With the individual having agency and being "intrinsically active", psychologists should be looking at not "why we act in the first place, rather in what direction [our] activity is likely to carry [us]' (Neimeyer, 2009). With experience through Kelly's lens being intrinsically linked to the individual, methodologies for understanding human experience through study came about. Kelly himself proposed the concept of the repertory grid in 1955 as a method of eliciting the "personal dimensions of meaning that a client uses to structure some important domain of experience". Repertory grids are used as a method of visualising elicited constructs from an individual in an attempt to understand the individuals experience of a subject matter. In the context of this study, we can consider reverberation to be the experience we are looking to elicit information about. Since participants will have individual constructs regarding various locations and their respective reverberation characteristics, elicitation techniques can be used to map out how individuals discuss their own experience. In order for a repertory grid to be successful however, constructs need to be elicited from the participant.

Constructs are "bipolar dimensions that allow us to understand, organize and anticipate events, people or objects in our world" (Caputi and Reddy, 1999). Two common methods for gathering constructs are the use of either dyadic or triadic elicitation. Dyadic elicitation asks the participant to consider whether two elements share a similarity or difference. If they share a similarity, then the antipole becomes the participants perceived opposite

description of the similarly. If the two elements share a difference, then the respective qualities become the pole and antipole of each other. Similarly with the triadic approach, the focus is to elicit constructs, however this time using three elements. Participants are asked to choose two of the three elements and suggest a reason in which they are similar, whilst proposing a reason why the remaining element is dissimilar. When deciding between which approach to use, studies have shown that while similar in their undertaking, the constructs elicited are method-dependant. Caputi and Reddy found that "the triadic method of elicitation seems to produce constructs that are less functionally independent, more meaningful in that they are better able to discriminate among elements. This method generally elicits construct sets that are more cognitively complex" (Caputi and Reddy, 1999). They also found that "participants tended to focus first on the positive attributes of the elements", whereas the dyadic approach gave a more balanced approach to both negative and positive attributes earlier on. They note an interesting result in that triadic sets of elements produced more antonym pairs for elements.

Elicitation and Audio

With the introduction of audio, research can begin to look at audio-specific elicitation methods and how the current methods of elicitation in non-audio human experience can be utilised for audio studies. Francombe, Brookes and Mason present a study into elicitation with spatial audio (2017) and found that "a very large dataset was collected, and it is likely that some of the elicited responses are more important than others". The study concludes with a series of constructs that were elicited from a series of experienced and inexperienced listeners. These were then categorised into various labels with poles based on the constructs. This seems an appropriate approach when using reverberation as a stimuli due to the parallels between reverberation as a concept and spatial audio, the focus of the study. A concern here is the use of stimuli in the study. It is proposed that this project will use a survey void of stimuli and a second study with aural stimuli. Francombe, Brookes and Mason suggest "using a multiple stimulus presentation when conducting a free elicitation (as in may help to mitigate [long answers with repetition]" (2017), though due to the focus on precognitive experience with reverberation in the survey, this may have the adverse effect of making participants discuss the stimuli rather than their own experience. As such, it was determined to keep stimuli in the second study and remove them from the first. They also note that "the large set of terms may be due to the fact that the elicitation was long and listeners felt the need to write different terms rather than repeating themselves, regardless of the instructions given". In the design of studies for this project, it is important to be conscious that large datasets will likely exist and also from a diverse spectrum of participants. They continue to discuss that "there is a degree of

agreement between experienced and inexperienced listeners, but some attributes were unique to the experienced listeners (mainly technical terms) and others were unique to the inexperienced listeners" (2017). In the case of the studies conducted for this project, users will be asked to describe their experience in chosen fields that relate to the study. However, this is open to interpretation when analysing as there is no categorical method to assess the skill of the participant such as an entry level test, and in turn they will be asked to self-assess and provide a result.

Precognitive Understanding of the Reverberation in Physical Spaces

In order to gain insight into non-auditory representations of reverberation, a survey was designed to capture information from participants and their precognitive/memorable approaches towards the reverberance in a series of physical spaces. Participants were asked to draw from their own experiences and memories with the aforementioned locations and to verbosely describe and discuss the reverberation they recall from associating with the space.

Survey Data

In total, 55 respondents participated in the survey, 28 of which identified as male, 25 as female, and 0 as non-binary. Most participants were between the ages of 18 and 34, with less respondents in higher brackets. Data was stored through the Qualtrics platform, and then exported, anonymised, and stored via an encrypted web-based platform.

Survey Design

The aim of the survey was to present a series of specific open questions with little direction in order to elicit the participants own method of response. If participants each have their own personal experiences and constructs of space, it is important to allow them to elaborate on their thoughts with only guidance towards the topic in question. The beginning of the survey introduces the topic with a brief explanation of what reverberation is functionally. It is then mentioned to "…be as verbose and descriptive as possible - describe in your own words exactly what you mean" in order to ensure the participant that they should talk as much as they deem necessary.

Due to the scope for the application of this research to interactive digital contexts, particularly video games, respondents were given the opportunity to declare any knowledge they had towards music, audio technology and video games. These answers are subject to the personal bias and judgement of the respondent, and as such are not accurately compared against any measurement or scale of knowledge. Regardless, justification for respondents' knowledges came primarily from the presence of a degree in a relevant, industry work in each field or a general interest in the form of a hobby.

Table 1 - Breakdown of study participants

Discipline	Amount of Respondents	Extremely Knowledgeable	Very Knowledgeable	Moderately Knowledgeable	Slightly Knowledgeable
Video Games and/or Video Game Creation	18	1	3	10	4
Music and/or Music Performance and Theory	25	4	4	13	4
Audio and/or Audio Technology	18	4	7	6	1

Design Evaluation

A simplistic survey was a successful approach for this study. In providing the participant with limited information or stimuli on reverberation, they were encouraged to rely on their own interpretations more, giving a more personalised set of responses. In using larger, open text boxes for the study, participants tended to write more verbose answers in a conversation-like style. This did however create large datasets with lesser amounts of respondents. While large datasets are ideal, more optimised practices for handling and analysing the data should be implemented. With smaller datasets, it is feasible to read through as a researcher, but the easily distributable nature of online surveys does allow for many more respondents to be reached, which calls for further exploration of software such as NVivo.

A difficulty in this study was describing reverberation without aural examples. A description of reverberation was provided, but it was a challenge to discuss this without using technical jargon or without incorrectly generalising terms. Many participants

understood echo and reverberation to be very similar, though in reality they are relevant to two similar but ultimately different things, with reverberation being the overall set of acoustic characteristics and echo being a feature of it. Removing bias from the survey was pertinent to make sure the responses were as much from the participant as possible.

Triadic Elicitation with Digitally Reverberated Audio Samples

A secondary triadic elicitation study was designed and piloted to provide a secondary approach elicitation for reverberation, however this time with an aural stimuli. The study is comprised of an audio listening test, asking participants to listen to three audio samples of various anechoic recordings that had been digitally reverberated using convolution reverberation and specific location impulse responses. Participants would be asked to verbosely describe the similarities between the reverberation in two of the samples whilst elaborating on a potential difference that the third sample had. The survey was designed and created using the Unity game engine and piloted with one participant.

Study Design

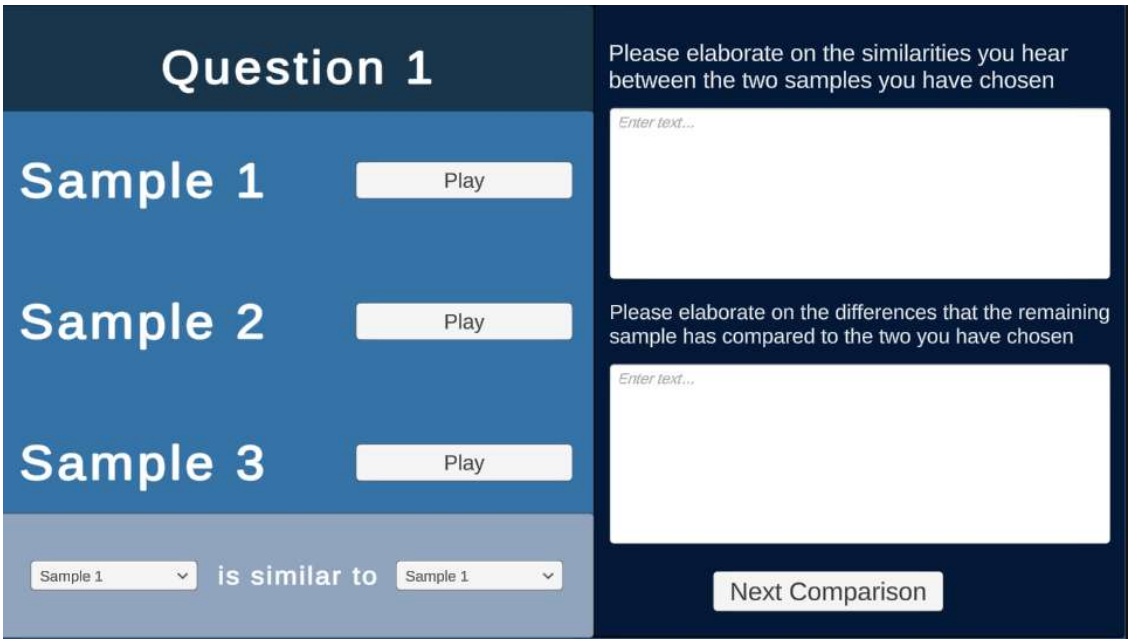


Figure 1 - Question template for participants

This study is focused on the use of triadic elicitation methods to elicit responses pertaining to three audio samples. Participants were briefed in the software beforehand, being asked to consider how the reverberation affects the content of the audio clip. Also, a brief outline on the question format is presented, explaining how to complete each question. Each question presents the user with three non-descript samples that they can play or pause at any given time. A sample content type is chosen (male voice, violin, horn etc) and then a reverberated version of that sample is chosen from the relevant category randomly when the question loads, meaning each sample has the same core content, albeit with a different reverberation applied to each. The user is not made aware of any information regarding

the reverberation sample, though this data is stored in their master file for use by the researcher. The user is prompted to choose which of the two samples best share a likeness in terms of their reverberation. Then, they are asked to firstly elaborate on what the similarity is between the samples and how that presents itself. Secondly, they are asked to suggest reasons why the remaining sample differs from the other two. The user can then move on to a new set of audio samples, with their results being saved to a master text file for analysis afterwards.

Survey Respondents

Due to this survey being a pilot study, only one initial participant was asked to complete it. Due to COVID-19 limitations, organising large amounts of safe in-person interactions was difficult, so the study was tested with a single participant in a controlled environment complicit with government guidelines. Additional work needs to be undertaken to make the survey successful across various platforms and devices, and as such was not distributed online due to it not being able to be tested across various devices and users.

Design Evaluation

For a proof of concept, the survey functioned well for its intended purpose. A system was written focusing on extension through drag-and-drop elements and template-based questions so that the program was versatile and expandable should it be necessary. It fulfils a simplified version of triadic elicitation, allowing for participants to be given three options to choose between. However, the digital nature of the program meant that the study felt static and allowed for little diversion from the core program. This might have the potential to let participants fall into routine by answering questions more repetitively since the questions are also repetitive. There are two remedies for this: the study would function well as an in-person series of case studies, inviting users in to listen to the samples with the researcher and to elicit responses verbally rather than through a software. This would give participants more spontaneity with completing the study and also the chance to communicate more subconsciously, rather than writing and editing answers for the current study. A second remedy would be to give further thought to the user experience of the program, adding in additional features to break the cycle of listen -> answer -> progress. This could be through randomised prompts, momentary breaks from answering, progress bars or improved visual design to foster further interest. However, as an initial exploration into digital triadic elicitation, the study proved successful in eliciting comparative responses from respondents that could be used in further reinforcing elicitation studies such as repertory grids.

Results

Study One – Precognition Survey

Approaches to Data Analysis

The results for this study were approached with a thematic analysis approach. The data set was first considered holistically to identify the most common themes present in the language used in the data set when describing the space or reverberation present in the space. In doing this, three themes became present. It is important to note that terminology used may not be exclusive to each theme; words such as 'dull' could be used as a description of a dullened sound, or how a room dullens the sound, for instance. In these cases, the phrase was coded to be referenced and considered by both themes.

The themes are as follows:

- Descriptions of the way sounds are filtered by the space

  Terminology relating to audio, sound physics and frequency content such as 'bassy', 'tinny', 'echoey' and 'loud'.

- Descriptions of space and physicality

  Terminology pertaining to size and material composition such as 'reflective', 'long', 'big', 'dense', and 'narrow' .

- Descriptions of the experience provided by being a listener in the space:

  Terminology pertaining to the experience of the space or sound in the space such as 'overwhelming', 'stifling', 'mysterious' and 'eerie'.

Considerations for Biased Data Analysis

Due to the method of analysis present, it is important to note the potential for influence of researcher bias on the results extracted from the dataset. The researcher acknowledges this and has analysed data as impartially as possible.

Distribution of Language

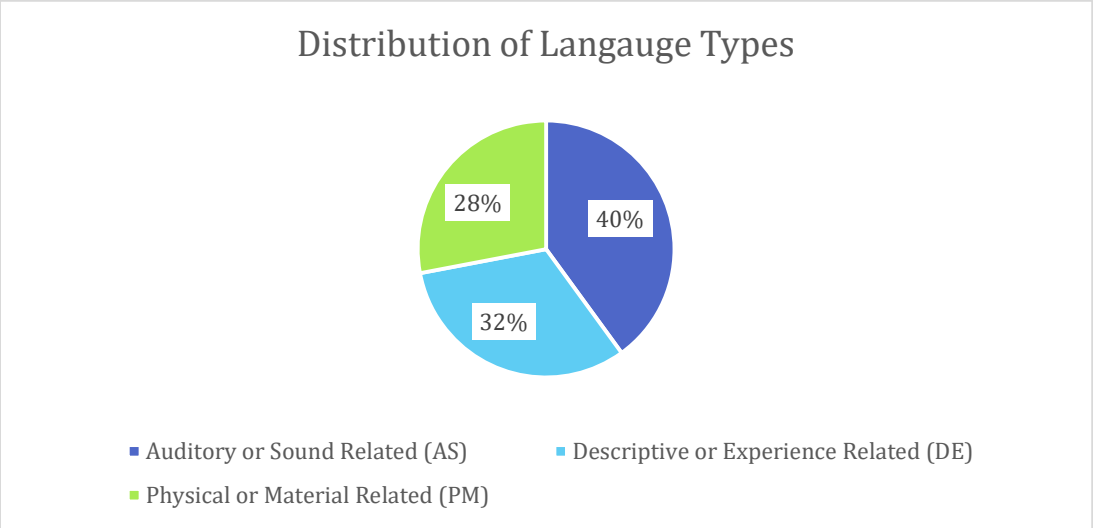


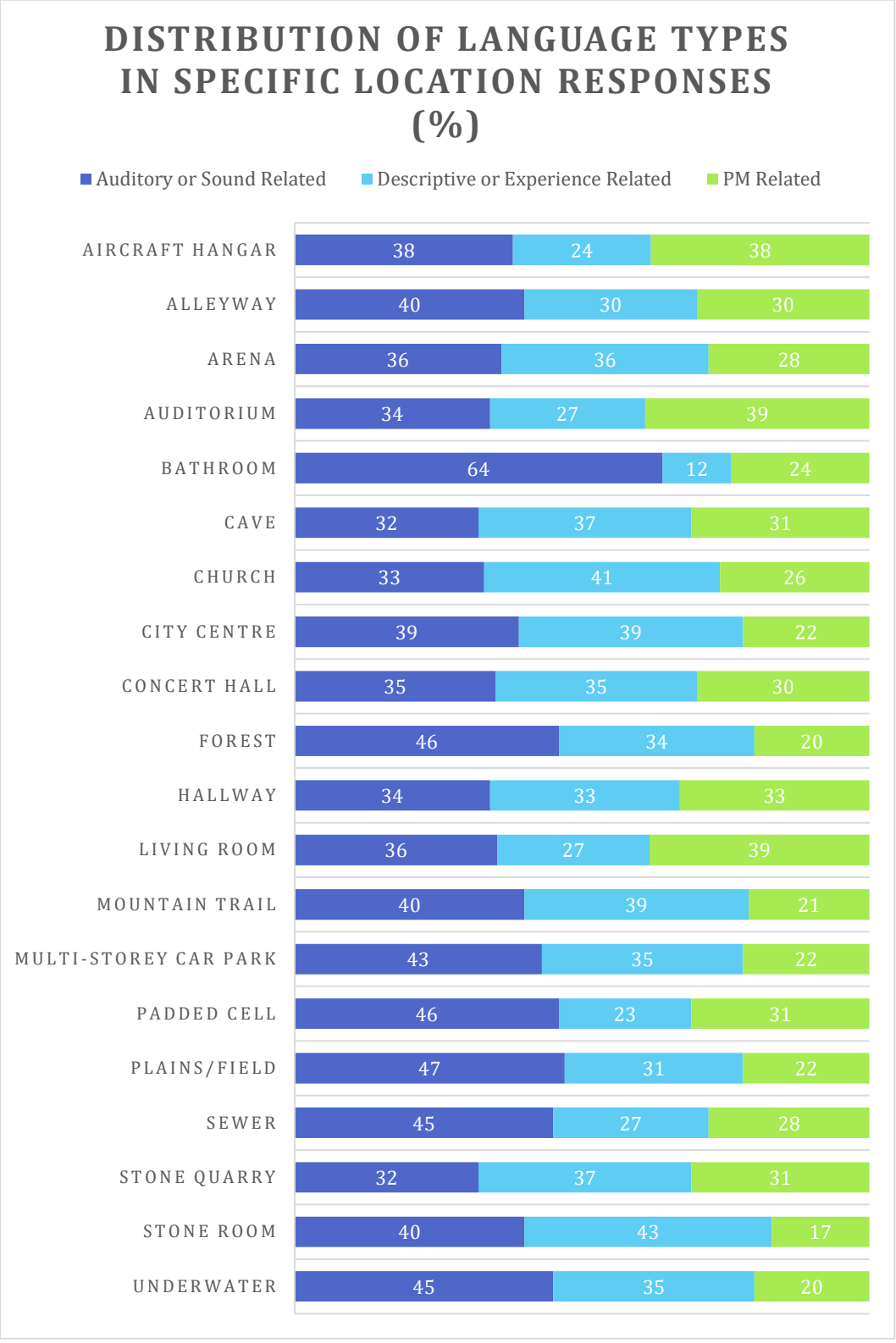
Figure 2 - Pie chart showing language type distribution

Figure 2 showcases the thematic distribution of language amongst the responses. There is a margin of 12% between the most commonly used type of language (AS) and the least common (PM), however only 4% difference in use cases between descriptive and experience and physical and ma. Given the context of the survey and the focus of describing reverberation from previous experience, the results showcasing a preference towards describing with AS terminology is expected. It is thought that the prompt to describe reverberation is a causal factor in the higher percentile of usage and that the precognitive approach to describing locations with no visual stimuli encouraged participants to recall events and experiences rather than locations, and in turn being inclined to remember feelings and emotions as opposed to the physicality of a space.

Below is a presented version of quotes and summaries for each of the interviewed locations. These summaries provide guidance on descriptive features elicited from the survey.

Location Analysis

Table 2 - Weightings for language types discussed



Aircraft Hangar

The language used in describing aircraft hangars focuses primarily on the physicality of the space, with participants alluding to the vastness of hangars. Noted are descriptions of "vast space", "enormous space" and "large space" and "cavernous". Also mentioned is the length at which sound could travel in the space, such as "large travel distances" and "the sound would travel very far", and the bounciness due to the flatness of the walls. One response also mentioned the shape of the space, noting that "the shape would probably make [the reverb] quite confusing".

Regarding common reverberation characteristics, "lots of echo(es)" was mentioned, again reinforced by reference to largeness of the space. This was paired with reference to longer reverb times, the metallic nature of the space and the "tinny" nature of the reverberation. Contrastingly, many participants described the reverberation as "muddy", "bassy" "washy", "confusing" and having a "lack of clarity", with one participant going calling the reverberation "blurry" and creating an "overwhelming hum". Generally, the discussion towards frequency content here is that the metallic nature of the spaces construction and contents allow for many high-frequency reflections, but the vastness of the space allows the "[reverb] tail [to] probably be so long as to blend into itself" and that "it would feel like the sound was stretching up very high into the air and then filling all the space".

Some participants hypothesised about reasons for this reverberation based on their understanding of the space, with examples such as "they are probably designed to minimalise noise reverb for safety reasons due to engines?" and "as they are large, mostly empty, spaces which are usually made of metal, which sound bounces off of rather than being absorbed". However, contrastingly some users were unsure on how to answer as they had never experienced the space for themselves, noting examples such as "N/A I have no idea", "I can't say that I have been in many aircraft hangers" and "I'm not sure on this one as I can't recall being in one!".

Alleyway

Despite allusion to the physicality of alleyways in the responses, it is the experiential terminology that poses interest. Participants are noted using descriptive phrases such as "alleyways seem spooky though", "alleyways are very enclosed", "mysterious", "ghostly and "scary dependant on the context". This could be inferred to be reflected in the physicality descriptions, with references to the length and narrowness of alleyways. Participants note that "the sound would carry due to the closeness of the two walls", "very directional, you almost hear the direction of it" and "directional, for sure. Facing down the alley would offer little chance for sound to bounce back at you".

Also are mentions on how sounds echo down the alleyway and are lost/decay, with one participant stating "if one clapped, they would hear the quick and close reverberation off of the walls next to them, and then residual reverberations that bounced away down the alleyway" and others also mentioning the lack of a roof/covering, with similarities being drawn between general outdoor spaces or caves. The reverberation is also characterised as being "dull", "hard" and "cold", with these characterisations often accompanied by references to stone and brick surfaces such as slabs and walls.

Arena

While not directly referencing arena experiences, participants are very descriptive and tended towards positive or powerful terminology in their responses. Examples of such are "lively" and "pleasing, "excitement" and "trepidation [sic]", "roaring" and "fierce", "expensive", "resounding" and "powerful". Given the nature of experiences one might have in an arena, such as music concerts or sports events, it seems appropriate that the memory of sound in such a space holds a positive space for participants. The issue here is that the answers seem to allude towards the sounds present in the space, rather than the filtering provided in the form of reverberation. However, when discussed, participants are aware of the size of the space, with notes that sounds travel far, have longer decay times, and have fewer noticeable echoes. Frequential content is isolated to be bassy and thick due to sound travelling further and around you to reach you, with one participant mentioning feelings of "excitement [and] trepidation as the sound surrounds you", and another saying "you can tend to feel the vibrations of the music going through you as the sounds is so loud", qualities typically associated with lower frequency ranges. Interesting here is that while sounds are "boomy" and "messy" to some, other participants mentioned that "even at the back of the arena you can hear the sounds really well" and that the sounds are "clear cut", perhaps suggesting a disparity in how varying venues acoustically treat spaces to control reverberation and frequency filtering.

Auditorium

Similarly to the descriptions presented for the arena, auditorium reverb descriptions spoke of how perceivably 'good' the reverberation is, however in this case with words perhaps considered to be more aesthetic and descriptive. Phrases and terms such as "very alive and detailed", "professional", "controlled" and "classy", "encapsulating", "great acoustics" and "resounding" are present. Attention is given to the reverberation allowing sounds to be "clear cut" and "sound travel[ing] well around the place". The thoughts on reverberation seem to relate to a 'controlled' sound. Consideration is given to the effect of soft materials or bodies being present in the location, with many participants noting short

and clear reflections, filtering sounds to feel “warm”, “vibrant” and “focused”. Additionally, some participants mention a “dull” or “muffled” sound to the reverberation, again likely referring to the dampening effect of present materials and bodies such as curtains, seating and other listeners in the space. This poses a contrast to the terminology used in descriptions for arena experiences such as “lively”, “exciting”, “roaring” and “fierce”.

Bathroom

Bathroom reverberation focuses heavily on the auditory experience from sounds originating there. Due to the commonality of ceramic tiling in bathrooms in modern homes, it is understood that many participants may share similar bathrooms and thus a similar auditory experience. Participants mentioned they sing in their bathrooms, and that is what allowed them to comment on the reverberation. Comments such as “makes you sound better at singing”, “the neighbours have commented on the occasional singing”, “if you make a sound/sing in a bathroom you tend to experience a fair bit of reverb” and “the sound bounces off the walls giving a nice acoustic (hence why lots of people record themselves singing in a bathroom)”. This is likely due to the resonance of bathroom being equated to that similarly of the lower frequencies of the human voice. The bathroom will ‘enhance’ the sound of singing through the resonation of warmer frequency ranges in the lower end of the frequency spectrum. Again, there are many references to the positive enhancement of sound due to reverberation, with comments suggesting that bathroom reverberation is “melodic”, “luxurious”, “very opulent” and “very good”. Further descriptions of the reverberation make note of the hard and flat tiled surfaces in the space, creating lots of “fluttery” or “clean” echoes and reflections. There were also descriptions towards the spaces feeling “close”, “small” and “intimate”, with one participant noting “given that there's usually only one, maximum 2 people in a bathroom at any one time typically, it would be similar each time it's experienced”. These references also appeared with the statement that reverberation makes sounds louder due to the reflectivity in such a confined space.

Cave

There is a change in tone when discussing reverberation in a cave; the descriptions feature words with potentially negative connotations. Phrases such as “sound in a cave seems to continue into an endless realm of echoes”, “unpredictable”, “complex”, “eerie”, “stuffy”, “unfamiliar”, “daunting” and “scary” are used to describe the reverberation. Auditory-focused descriptions focus on the reverb being long, low, distorted and bassy. There are references to the echoes created in such a space to “cause disorientation”, create a “messy echo” and “echoing giving different pitches depending on the cave structure”. The

physicality of the cave being uneven and rocky seems to elicit responses that outline unease or confusion. Further references may relate to the emptiness or lifelessness of the space. Some participants describe the reverb as “dead”, “cold”, “hollow” and “trailing away” or “continuing into an endless realm”. There is an element of bleakness in the terminology, which is somewhat distant from the overtly echoic descriptions mentioned earlier. There seems to be a disparity in the holistic feeling or experience of the space’s reverberation and then what the listener thinks they are hearing; liveliness and messy echoes contrasting with a cold and hollow overall reverberation.

Church

Religious and grand terminology are present in participant responses here, such as “immense”, “gospel”, ”beautiful”, “hypnotic”, “heavenly”, “strong”, “holy” and “overwhelming”. When analysed against the physical-related descriptions, many participants make note on elements such as “those old cathedrals were soaked in reverb because of the tall stone architecture”, “certain ancient churches had excellent reverb due to stone construction”, and “churches tend to have high ceilings and large stone/brick walls, which creates a wonderful space for the sound waves to project off of”. Regarding auditory discussions, there is a distinct lack of reference to echoing, unlike other examples. Instead here, many participants note how there is “definitely more [reverb] than a normal room, similar to an arena”, “lots of reverb! Those old cathedrals were soaked in reverb” and “big, powerful reverb” which is perhaps suggestive of a space that allows for higher reflections/dry sound ratio of sound to reach a listener. This also is parallel to the use of terms such as “immense” and “overwhelming”, since all sound is filtered in such a way that listeners are left predominantly with heavily reverberated sounds. Similarly, participants discuss the longer decay of the reverb being noticeable, with responses such as “you can definitely hear the sound lingering above you and still vibrating and echoing in that space after you’ve spoken/made a sound”. Interesting to note here and furthermore in the dataset are the references to voice and singing. Some participants referenced choral singing, gospel and choirs, and how listening to these sources of sound being reverberated is what provided a “pleasant”, “thick” and “rich” sound to the experience.

City Centre

When discussing the reverb for a city centre, some participants were unsure of how to do so, given the space is outdoors. Responses featured such examples as “not noticeable”, “barely noticeable amongst the sound of traffic”, “if it’s busy then very short sounds, not much echo”, “I'm unsure. It's hard to tell as there's so many different noises happening at once. I'd imagine if it's outside its pretty minimal” and “not sure I have noticed ,always to

noisy and confusing". There are also a notable amount of mentions for ambient and location-specific sounds, with many participants mentioning "noisy and confusing", "the sounds of cars are very deep", "barely noticeable amongst the sound of traffic", "sound mixed (bangs, voices, traffic) echoing around buildings" and "it's hard to tell as there's so many different noises happening at once". In the context of a city centre, there is a distinct preference towards hearing and recognising the soundscape present, less so the reverberance that affects it. Due to the longer, monotonous sounds found in city centres, such as traffic and construction work, for example, beds of sound are created with less noticeable transient qualities. Even then, quicker, impulse-like sounds, such as horns, shouts and objects clashing blend into the bed of the other sounds. This not only provides a large amount of variance in sounds to focus on, but also a lack of ease in understanding and deciphering reverberation qualities. Reinforcing this are such responses as "not too great if you wanted to focus on specific sounds", "sound doesn't die but gets lost" and " these [sounds] disperse quickly as there is nothing to hold these in". That said, dull and muffled echoes are mentioned due to the surrounding buildings and their material composition. Many participants mention short echoes that reflect off of buildings that are near to one another but say that the sporadic nature of reflections and the presence of an open outdoor space means that reflections decay quickly or are lost to the bed of ambience.

Concert Hall

Immediately it is apparent that warmth and bass are memorable factors in concert hall reverb. Respondents are noted stating "full bodied but with intention and direction, so it's like the front of me is washed over with it", "echoing with a tendency towards maintaining the bass notes", "a lot of bass with long sound dissipation" and "lower register is able to project more". Should participants be associating concerts halls with performances of orchestral music, orchestral instruments may be resonating at lower frequencies in the space. This is something that may have previously been designed for and utilised in architecture for performance space in the form of resonators (Polychronopoulos et al, 2013 and Kanev, 2020) as such may be indictive of why this experience of lower frequencies and warmth exists. There are references to the clarity of sound throughout the space and also how the location of the listener affects this. Participants state that "[the reverb] creates a feeling of space and distance even when you are relatively close to the orchestra", "varying depending on where in the hall, and if there are people in it", "from my experience with concert halls (mostly with orchestral concerts), even though they're usually large rooms, they can sound pretty intimate regarding reverb" and "concert halls are assumably designed for reflecting sound equally around the space for the benefit of an

audience, so I'd expect reverberations to travel clearly and equally around the hall". There are finally mentions on how softer materials provide a dampening effect on the sound, such as curtains, seats and acoustic treatment. Furthermore, references to the shared experience of the concert hall and how listeners provide their own form of dampening to reverb decay. Participants stated "depending on where in the hall, and if there are people in it. can be quite long and 'boomy'", seats, curtains will account for some absorption", "you can usually hear a lot of different sound from various places in the hall (chairs creaking, people coughing), even when you're far away from the source" and "plus any sound treatment in the hall will also help the sound soften up". Though the space will have reverberation without the presence of an audience, it seems that in many experience recollections, the audience is inherent in the description of the reverb, as if they are a permanent fixture for the space.

Forest

Participants mention that the reverberation in forests is low in amount or non-existent, however pertinent here is the lack of a uniform census as to what forest reverberation is. Some participants mention initial slap-like echoes, the dissipation of post-excitement echoes and the lack of directionality. Phrases such as it is "hard to distinguish where the sound is coming from", "disorientating due to the position of the trees causing the sound to come back from different directions" and "disorienting and fluttery, [with] loads of things to bounce off" are used to describe the reverb. Contrastingly, other participants mentioned the lack of reverberation due to it being outside. Phrases mentioned are "no reverberation. Sounds dies quickly but isn't flat", "low since its outside", "normal? It wouldn't sound like it would be affected" and "maybe not a lot of reflections going on, but no intimacy to it, as you're not really in a closed space". One consistent thought however is that sound travels far and is lost, rather than being reflected back to listener. Listeners did not expect to hear their voice come back to them when shouting, with one participant highlighting "but when you walk dogs (and loose them) and then shout for them you don't hear an echo of your voice. You can hear noise in the distance (the dog barking) and can judge the distance of how far away he is pretty well". This is reinforced through other responses discussing the quicker dissipation of sound in the space, only being able to hear sounds that are coming towards you and sounds being "far-reaching" and "[getting] lost compared to an enclosed space".

Hallway

The most prominent discussion with hallway reverberation is the longer, narrow nature and how sound travels along this. Statements such as "the hallway I'm thinking of is

narrow and long, so active reverberation from the sides but any along the hallway gets lost", "narrow, enclosed, uniformed", "similar to alleys, in that you would likely hear reverberations from perpendicular intersecting hallways moreso than from your own", "it would feel elongated and almost echoing" and "reverberations would bounce away down the space and give a longer tail to the reflections". Some participants acknowledge the presence of reverberation, however that it is subtle, low or unnoticeable. Key phrases include "not always there", "never really noticed", "not a lot going on in terms of reflections but doesn't actually sound dry" and "some reverberation depending on material. Neutral sound.". The key feature that participants recognise is a lengthier reverberation tail due to the length of a hallway and also the comparison to an alleyway, albeit with hallways having the inclusion of a roof. This prompted participants to suggest roofing to be a reason for extended reverb tail times, with one particular response highlighting "the ceiling of the hallway differentiates it from the alleyway, adding another surface for reflection and likely resulting in further reverb decay time". A few responses mention annoyance or sharpness in higher frequency reflections in a hallway. Responses such as "annoying I would say, as though specific frequencies are more piercing", "an [sic] quick sharp echo" and "a high-pitched ring as the sound comes back from something hard like a lampshade or the door". Finally, there was one instance of ambiguity as to the type of hallway since none was specified. Most responses alluded to a hallway in a home, however one respondent also considered a school hallway, noting "high school hallways would be better reverb candidates due to lockers, though students' bodies would absorb sound, while contributing to the white noise customary to bustling corridors". This is perhaps indictive of a need for visual stimuli or visual descriptions to better confirm the perceptual fidelity between a heard reverberation and a space on a screen.

Living Room

The general census for living rooms is that the reverberation is unnoticeable or present in a low amount. There is also prominent mention of absorption due to carpets, cushions and sofas. Parallel to this is that some participants do not pay attention to the reverb. It is hypothesised this is the case due to how frequently people use their usual living rooms (see Khajehzadeh and Vale, 2015), and in turn become desensitised/accustomed to the reverberation there. One participant noted the reverberation of an empty living room such as "dry, flat, potential flutter echo and resonance if empty" but most descriptions included furniture. Other physical descriptions mention room shapes and sizes and it is it important to note here the disparity between experiences based on personal living rooms. Phrases such as "it depends on the size of the living room and the height of the ceiling, but I can't think of a time where I've paid attention to/noticed any reverberation in a living room",

“usually little to none, if it a typical house (like 4x7m or so), not noticeable”, “square living rooms have quick reverberations from hard, symmetrical corners”, “I live in a small apartment with a lot of furniture in it, so consequently there is a low reverberation” and “depends on the size of your room I suspect. Personally, I have small rooms so don’t really notice much reverb“. Generally, participants recognised living rooms to be smaller, furnished spaces which dampen/absorb reflections and offer them negatable levels of reverberation, of which the tail was not prolonged and decayed quickly.

Mountain Trail

Many participants note the softer and passive nature of a mountain trail reverberation, suggesting it is akin to forest reverberation. The core reverberation parameter mentioned is the presence of initial echo or slapback. Phrases reinforcing this are “same description as Forest, I would say”, “a lot of echo if the sound is projected as it comes back off of mountains within close proximity”, “similar to a forest - perhaps a less dense part” and “no reverb, if any there will be one or two slap backs considerably separated from each other”. Other opinions suggest a spacious reverberation due to the outdoor context and thus the lack of surfaces for reflections. Quotes such as “a mountain trail would cause no reverberation as there is nothing for the sound to bounce off of because it is so open” and “Have to speak up to be heard, no echoes” suggest that reverberation is hard to hear because of the lack of echo-producing surfaces. Contrarily, other participants discuss the presence of echoes, but a lack of localisation. One response states “you can hear the sound you make very clearly bouncing off the trees around you but when hearing other sound, it’s very difficult to pinpoint where it’s coming from as it can bounce in so many different directions”, and other saying “a lot of echo if the sound is projected as it comes back off of mountains within close proximity”. One unique feature to notice in the reverberation descriptions here is the pairing of the sound with softness and quietness. Quotes such as “airy”, “peaceful”, “slow”, “soft”, “more natural” and “calm” are all used to describe the reverb. This could perhaps be due to connotations of mountain walks being a peaceful experience, or the presence of nature in a participant’s memory of this location.

Multi Storey Car Park

Participants note a larger, lower/bassier and louder reverberation, and also mention the density of the building’s materials, as well as the lack of side walling. One verbose description states “some reflections from cars, floor and ceiling will result in a perceived reverb however, due to the nature of the environment this won't be a long reverb or overpowering reverb as there are plenty of ways for the sound to escape and not be reflected back”. Many responses follow suit in this understanding, with others saying

“fairly echo-y again but like an arena, the sound seems forced inwards and amplified”, “multi-storey car parks typically have big concrete pillars and are fairly enclosed”, “bouncy, dull reflections, lots of stone and cars to bounce off but also space to escape out the sides” and “lots of reverberation yet more dense. As if the storeys block the echo from travelling in between floors”. Participants also talk about the presence of noise from vehicles being a factor that creates loud noise in the space. Other participants talk about a confusion as sounds come from many directions, and there could be links to how the reverberation is understood here. With drone-like engine sound coming from various source locations, it is feasible that the reverberation would be harder to understand due to the lack of impulse-like sounds and multitude of sound sources to give attention to. That said, some participants do mention the presence of echoes. “very reverby, but scattered due to support columns”, “fairly echo-y again but like an arena” and “if you made a sound in one it is like to cause reverberation due to the size of the space and the many surfaces the sound can bounce off of”. A final note here is the drawing of parallels between spaces. Some participants likened a car park to other spaces. “similar to a stone room”, “maybe the same description as the one for a sewer” and “fairly echo-y again but like an arena”.

Padded Cell

There seems to be a common understanding for padded cells to deaden sounds that are in the room, providing little to no reverberation. Participants understand sounds to become muffled and dull due to the filtering of the space and for the general size of the reverberation to be small. Quotes such as “almost none existent. All sounds seems to be soaked up”, “Non-existent, reverberation gets absorbed by padded wall”, “low reverb, the padding soaks up the sound” and “there wouldn’t be much sound due to the room being covered in the pad material” suggest that participants are aware that the padding itself plays a large role in characterising the reverberation. What is interesting here is the descriptions on experience that some participants provided. Phrases such as “Dead. Sterile”, “Dead, dry, mind-bending”, “basic”, “stifling” and “dull monotonous and boring”. There seems to be a link between the experience of sound in the space and feelings of boredom and monotony. This could be parallel to research conducted/news reported from anechoic chambers and links to an increased awareness to the lack of external sound and also one’s own sound production. Steven Orfield of Orfield Laboratories explains this by saying “You’ll hear your heart beating, sometimes you can hear your lungs, hear your stomach gurgling loudly. In the anechoic chamber, you become the sound” (Claridge, 2020). With padded cells providing a similar scenario to anechoic chambers in the removal and deadening of reverberation and perceptual cues, it is understandable why some listeners may experience the space as ‘mind-bending’.

Plains/Field

A similar theme throughout the outdoor spaces here is the understanding of little to no present reverberation. Many participants mention this: “I don't think I could say there was any”, “little to no reverberation since nothing to reflect off”, “not a lot of reverb. Lots of room for sound to escape. Little perceived reverb” and “open expanses allow sound to dissipate, but the lack of reverb (and the very small amount of reverb that comes back off of the floor) would signify to the listener that they were in an open space”. Other participants recognise a softness and naturalness to the way sound is reverberated. “soft, quiet and more natural, like in the woods”, “sounds are more direct and clearer”, “open and free, no echo meaning more things can be heard e.g. birds/animals” and “open, bright, natural” suggest that the lack of filtering by environmental impacts allows for a more pure and easy listening sound. There are also references to the distance sound has to travel and how the lack of reflections makes hearing difficult. Many participants mentioned that sound becomes much fainter as it travels away from the source, as well as needing to speak louder if they were doing so to another listener. Interesting here, compared to the padded cell example, is that the lack of perceptual cues seem less affecting in the outdoor space. Though both spaces feature low to no reverberation, the outdoor context seems to provide a better experience than the cell, perhaps suggesting a bias in importance towards non-aural stimuli in these situations.

Sewer

Participants seem confident and consistent in their understanding of sewer reverberation. Four responses drew conclusions from comparisons to a cave, stone room or by their understanding from movies while a few participants mentioned not knowing how best to describe the reverberation. Most participants isolate a significant echoing with a reverb tail long in length, with many attributions to the shape of the space. Quotes such as “extremely echoey and the sound would travel very far”, “a long is enclosed tunnel creates a great space for sound waves to bounce off of”, “echo and possibly lots of reverberation given the close walls and little space between them” , “very very echoey. Sounds will ricochet around the walls” and “very reflective due to possible domed ceiling and hard brick” reinforce this. There seems to be a solid understanding of sewer physicality amongst participants. One feature mentioned by participants is the difference when water is present. Phrases such as “smooth surface pipes would be very reverberant, assuming water levels aren't too high” and “I imagine the more water in the sewer the less reverberation there would be, since the water would absorb the sound” understand water to be an absorbent material. Only one participant spoke explicitly about the context of the space providing a negative experience, stating “foul, confined, claustrophobic, smelly,

dangerous", though it is unsure as to whether this describes the reverberation or the space itself, furthermore if there is a link between them. Some participants mention the frequency content of the reverberation. Some statements acknowledge a higher bass presence, such as "a low humming sound where the bass of the sound is reflected back off of the brick walls" and "long lasting and good bass", while some mentioned high-frequency content, stating "very metallic sounding as it reflects off of hard surfaces such as metal ladders or piping" and "lots of reverberation going on, and mostly reflections that sound bright. A few participants stated that the reverb made sounds in a sewer difficult to understand, with phrases such as "if you had a choir singing in there, most likely the words would be hard to perceive", "a sewer would also start sounding washy if a lot of acoustic energy was being spread" and "Intensely reverberated sounds due to the shape of the sewer".

Stone Quarry

Overarchingly there inconsistency between participants. Many had never been to/did not know about reverberation in a stone quarry, with some guessing or questioning their answers. Some mention "absolutely no idea", "no clue", "I really have no idea on this one" and "I am not sure, as I do not think I have been to one". Others question or doubt themselves with responses like "you may well get an echo!", "I also don't know, perhaps because of the big space not much at the top but a lot at the bottom??" and "I'd imagine pretty reverby too!". For those who did comment on the reverberation, the answers were multifarious, ranging from "similar to that of an amphitheatre", "maybe almost a mix between the stone room and forest descriptions" and "somewhat bouncy, bit like the cave but not as extreme" to "not much echo and perhaps slightly muffled due to the density of the stone" and "prolonged repeated sound of the work taken out in the quarry. Loud and lasting years" Generally, it seems participants understand there to be reverberation present but are unsure in categorising it This could be due to the lack of a sensory stimuli paired with the slight obscureness of the location causing more guesswork or aural and physical associative predictions (e.g. stones equal dullness, outdoors means no reverb).

Stone Room

Participants acknowledge that the way sound is reverberated in a stone room results in a series of brighter and more harsh reflections, with the space generally being very reverberant overall. Participants note that "[reflections] coming at you like a swarm of wasps (excluding the buzzing)", "again echoing but this time with a tendency towards highlighting the higher pitched notes", "mostly mid to high frequencies", "I would say

maybe a fair amount of reflections with a brighter sound overall?" and "almost tinny like a phone speaker". Unusually, in similar examples featuring a stone surface present, participants noted that sounds would be dullened by the stone, creating a less bright reverberation. This could perhaps be due to the presence of a full room of stone surfaces rather than just a single or few surfaces. Though many exclaim about lots of reverberation and bright reflections, some participants also note a quick decay time, citing the reverb to be "prominent but shorter, around 2 or 3 sec", "cold and slaps with a short tail" and "also the sound drops off much sharper". Some participants described their reverberation experience as "cold", "hollow", "harsh" and "distracting". These terms could perhaps be attributed to the perceived lack of lower frequencies associated with bass and warmth in sound, however manifesting in a more physical response rather than aural. Discussing the stimuli for their responses, two respondents mentioned their lack of experience in such a space, one referencing "I'm imagining an old cellar", and others referencing the size of the space they were imagining, such as "if there were lots of people in it, it would still be reverberant (especially if it's big!)" and "if it's a big room it carries".

Being Underwater

This location was used to offer a less common situation in which reverberation occurs. While there is not an open space of air for sound to traverse through, a situation is presented in which sound is heavily obscured and filtered before being 'heard' by a listener. While sounds may not be heard in a traditional sense, the effect of the water on a listener's eardrum still creates and filters sound, something which would not be understood by a person with reduced or no hearing. Participants largely recognise the muffling and distorting effects being underwater would have on sound. Phrases such as "Close, warped, alien", "Low-passed, Worbled", "it all becomes muffled and distorted", "stifled, groggy" and "claustrophobic, sounds would make me panic" reinforce this. Some participants did attempt to analyse the reverberation in terms of, or in relation to, non-underwater locations. Responses such as "the sound does carry further but it is less recognisable by the time you hear it due to the diffraction of the water", "sound travels faster in water than air, so reverberations would have an alien quality as they appear more quickly to your ears", "sounds are drowned out and not much resonance" and "I know sound carries OVER water pretty well but I'd imagine underwater it has a sort of dampening effect?" suggest that participants can try to comprehend the concept of reverberation in water and use air-based reverberation to do so. Extending this, one interesting observation here is that two participants mentioned references to sonar and dolphins, stating "dolphins etc can send out their sounds and hear each other from ages

away" and "Were I a dolphin or military submarine I would say that reverb underwater was amazing, should a fish etc be nearby. To humans, there is no reverb underwater".

Study One Summary

The results in study one showcase a series of common descriptions from participants regarding the reverberation in various physical locations. The results suggest that, while constructs for locations may exist for each participant uniquely, there is overlap in the intent for the description. Many participants described reverberation with similar or grouped wordings that, though pertaining to their own individual experiences, may be indictive of a shared experience of reverberation in a given location. Further construct analysis may isolate specific primary components for each location and suggest a series of terminology that is commonly understood by listeners in such a space. This terminology could then be employed in audio description or subtitles for instance, as an alternative method in communicating the way sound is experienced in the given reverberation of a space.

Study Two – Triadic Elicitation Pilot Study

While the first study provided insight into how a group of participants understand the reverberation in various locations from memory, the second study seeks to preliminarily investigate how participants understand audio samples reverberated through a convolution reverb with no contextual information as to the sound's representative location. Three audio samples are provided to a participant, with prompts asking them to choose two which exhibit a sonic similarity and to explain what this similarity is. Furthermore, the participants are asked to describe a difference that the remaining sample has compared to the other two. The table below outlines the reverberation samples used at each stage and the pair that were chosen as having a similarity.

Table 3 – Triadic elicitation results table based on participant results in pilot study

Sample Type	**Reverb 1**	**Reverb 2**	**Reverb 3**	**Similar**
Blues Guitar and Vocals	Amphitheatre 2 (half wetness)	Van (half wetness)	Home Bathroom 2 (half wetness)	1 and 3
Female Voice	Van (half wetness)	Town House Studios (half wetness)	Outdoors Desert	2 and 3
Horn	Small Room (Knights Hall)	Arena 1	Amphitheatre 2	2 and 3
Horn	Small Room Knights Hall (half wetness)	Amphitheatre 1 (half wetness)	Small Room Knights Hall (half wetness)	1 and 3
Horn	Small Room Knights Hall (half wetness)	Amphitheatre 1 (half wetness	Small Room Knights Hall (half wetness)	1 and 3
Light Gunshot	Church St Pauls	Home Bathroom 2	Masterphonics Studio	1 and 3
Male Voice	Outdoors Desert (half wetness)	Small room (Knights Hall, half wetness)	Home Kitchen (half wetness)	2 and 3
Male Voice	Home Bathroom 2	Arena 2	Small Room (Knights Hall, half wetness)	1 and 2
Male Voice	Arena 1 (half wetness)	Masterphonics Studio (half wetness)	Home Bathroom 2 (half wetness)	1 and 2
Paphorn	Town House Studios	St Pauls Church	Bus (half wetness)	1 and 3
Paphorn	Outdoors Desert (half wetness)	Amphitheatre 2	Church York	1 and 2

The results from the pilot study show both successes and concerns. As evidenced in table two, the study elicited a series of constructs from the participant. As discussed with triadic elicitation, the answers were indeed more complex, extending to discuss emotional

reactions to the reverberation, such as the responses “homely”, “eerie” and “intriguing”. This is where the digital format of the study offers pitfalls. While the descriptions here were valid, the lack of in-person discussion left little opportunity for the participant to clarify themselves on their answers. The triadic approach allowed the participant discusses to explore various differences and similarities between pairs and remaining elements. This meant that no explicit antonym or antipole was presented for every observation by the listener, only some. This means that the listener may have their own unexplored observations, but without the intervention for clarification or justification from the researcher, this is overlooked. This could be encouraged by the study asking explicitly for one similarity and one difference; this may be limiting to the potential of the study and as such needs further research.

Table 4 - Elicitation poles table generated based on Francombe Et Al (2017)

Label	Description	Scale End Points
Echo Amplitude	The perceived volume of echoes	No echoes – Lots of echoes
Pitch content	The perceived pitch of the reverberation	Low pitch – High pitch
Brightness	The perceived brightness of the reverberation	Dull– Bright
Size of Space	The perceived size of the emulated space	Small – Large
Warmth	The perceived warmth of the reverberation	Cold - Warm
Excitement	How exciting the reverb sounds	Boring – Exciting
Reverb Length	The length for which the reverb can be heard	Short – Long
Confinement	How confined the reverberation feels	Confined – Open
Ghostliness	How 'ghostly' the reverberation is	Not ghostly – Very ghostly
Sharpness	The sharpness of the reverberation	Blunt – Sharp
Distance	The distance from the listener the sound is perceived to be	Close – Far
Happiness	The perceived happiness of the reverberation	Sad – Happy
Amplifying Quality	The perceived amplification from the reverberation on the sound	Quietened – Amplified
Fullness	The fullness of the reverberation	Empty – Full
Speed	The apparent speed of the reverberation	Slow – Fast
Harshness	The harshness of the reverberation	Easy – Harsh
Clarity of Echo	How clear echoes are of a sound	Muffled – Clear
Intrigue	The level of intrigue from the reverberation	Not intriguing – Very intriguing
Prominence	The perceived prominence of the reverberation	Subtle - Prominent
Eeriness	How eerie the reverberation feels	Eerie – Fun
Character	How much character the reverberation gives to a sound	Less character – More character
Homeliness	How homely the reverberation sounds	Not homely - Homely

The table above showcases a collection of constructs from one participant that could then be furthered into additional confirmation via a repertory grid. Further research would mean that this study could be completed with additional participants and additional constructs. These results would allow for cross-reference analysis between participants to identify commonalities between reverberation characteristics and experiences.

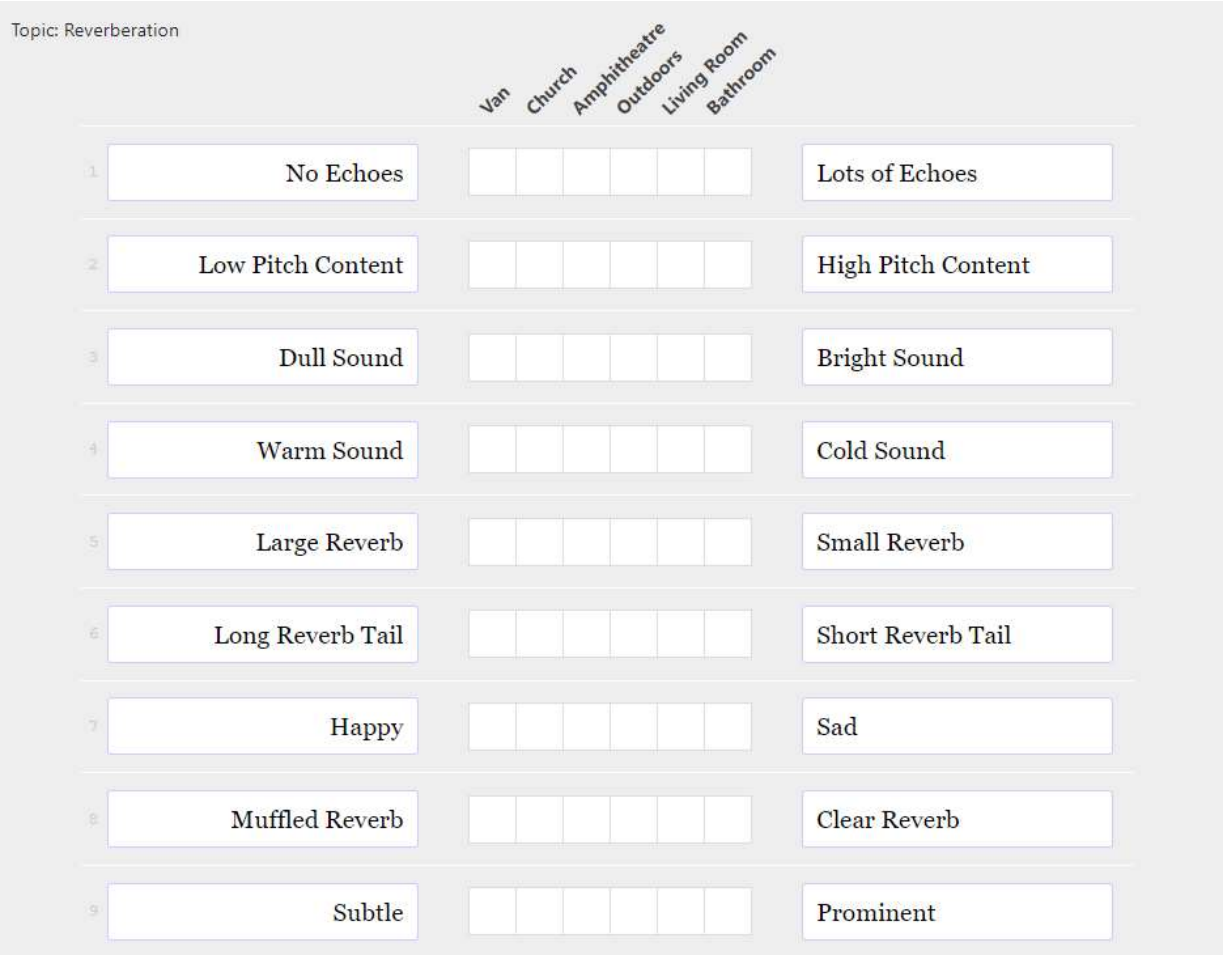


Figure 3 - An example RepGrid based on participant results

It is thought that such a method of elicitation would work well as a distributable format for larger participant groups. If the initial study were conducted on a larger sample, the data sets could be compared to reduce the number of constructs through principle component analysis. In doing so, a dataset that is representative of the whole, however with fewer constructs, can be created and distributed the repertory grid format to see how larger groups of participants understand and rate a common set of constructs.

Conclusion

This project showcases the use of elicitation in understanding reverberation through two studies. It successfully outlines common thoughts from participants in describing physical locations from memory, suggesting that a universality in sentimental perception may exist. Furthermore, the pilot test for study two showcases that triadic elicitation is a successful method for eliciting information on the perception of reverberation using an aural stimuli. It also outlines the potential use of repertory grids in reinforcing the results from participants and suggests that the approach could be used with large participant groups to work towards a common understanding. In eliciting an understanding in reverberation from both a precognitive and aural stimulus context, it is proposed that both better descriptions of and informed implementations of reverberation in could seek to create better senses of presence in digital interactive experiences. This project paths a way into developing improved practices in using reverberation in digital experiences, providing additional descriptive factors for those with accessibility concerns, and also works gives reason for further research to be considered in these areas.

Project Conclusions

The project provided a series of successful outcomes grounded in appropriate theory. Two studies were designed to elicit responses about the understanding and experience of reverberation from both a precognitive and aural-stimuli approach. While preliminary, the studies showcase methods that can be successfully applied to audio-focused elicitation, whilst also being grounded in literature that reinforces the reasoning for the methods used. Since the studies are dealing with personal experience, it would be desirable to have additional participants to complete the studies to provide a wider distribution of results. Furthermore, it would be ideal to have additional testing measures in place to reinforce the validity of the data, since there is involvement on the behalf of the researcher. Further work in this project would involve the development of better elicitation software specifically for audio focused work. The research would expand on the triadic elicitation studies to involve additional participants in order to work towards a more universalised dataset for analysis.

References

2003. *THE GAME ENVIRONMENT FROM AN AUDITIVE PERSPECTIVE*.

2020. *2020 Essential Facts About The Video Game Industry*. 1st ed. [ebook] Entertainment Software Association. Available at: <https://www.theesa.com/wp-content/uploads/2020/07/Final-Edited-2020-ESA_Essential_facts.pdf>

Ablegamers.org. 2020. *The Ablegamers Charity | The Worlds Largest Charity For Gamers With Disabilities.*. [online] Available at: <https://ablegamers.org/>

Barlet, M. and Spohn, S., 2012. *Includification*. 1st ed. The Able Gamers Foundation.

Barton, K., 2015. Elicitation Techniques: Getting People to Talk About Ideas They Don't Usually Talk About. *Theory & Research in Social Education*, 43(2), pp.179-205.

Bull, A., 2019. Class, Control, and Classical Music.

Caputi, P. and Reddy, P., 1999. A COMPARISON OF TRIADIC AND DYADIC METHODS OF PERSONAL CONSTRUCT ELICITATION. *Journal of Constructivist Psychology*, 12(3), pp.253-264.

Claridge, S., 2020. *The Longest Anyone Can Bear Earth'S Quietest Place Is 45 Minutes*. [online] Hearing Aid Know. Available at: <https://www.hearingaidknow.com/quietest-room-anechoic-chamber>

Consortium for Research in Deaf Education, 2019. *CRIDE Report On 2018/2019 Survey On Educational Provision For Deaf Children*. [online] National Deaf Childrens Society. Available at: <https://www.ndcs.org.uk/media/6063/cride-2019-uk-wide-report-final.pdf>

Darken, R. and Peterson, B., 2014. Spatial Orientation, Wayfinding, and Representation. *Handbook of Virtual Environments*, pp.467-491.

Dib, L., Petrelli, D. and Whittaker, S., 2010. Sonic souvenirs. *Proceedings of the 2010 ACM conference on Computer supported cooperative work - CSCW '10,*.

Duel, T., Frohlich, D., Kroos, C. and Xu, Y., 2018. Supporting audiography: Design of a system for sentimental sound recording, classification and playback. In: . Stephanidis, ed., *HCI International 2018 – Posters' Extended Abstracts*, 1st ed. [online] Las Vegas, Nevada, USA: Springer, pp.24-31. Available at:

<https://www.researchgate.net/publication/325663584_Supporting_Audiography_Design_of_a_System_for_Sentimental_Sound_Recording_Classification_and_Playback>

Francombe, J., Brookes, T. and Mason, R., 2017. Evaluation of Spatial Audio Reproduction Methods (Part 1): Elicitation of Perceptual Differences. *Journal of the Audio Engineering Society*, 65(3), pp.198-211.

Heffner, R. and Heffner, H., 1992. Visual factors in sound localization in mammals. *The Journal of Comparative Neurology*, 317(3), pp.219-232.

Kanev, N., 2020. Resonant Vessels in Russian Churches and Their Study in a Concert Hall. *Acoustics*, 2(2), pp.399-415.

Khajehzadeh, I. and Vale, B., 2015. How do people use large houses?. In: *The 49th International Conference of the Architectural Science Association 201*. [online] Melbourne. Available at: <https://www.researchgate.net/publication/293817304_How_do_people_use_large_houses>

Lahav, O. and Mioduser, D., 2005. Blind persons' acquisition of spatial cognitive mapping and orientation skills supported by virtual environment. *International Journal on Disability and Human Development*, 4(3).

Lopez, MJ 2015, Perceptual evaluation of an audio film for visually impaired audiences. in *Audio Engineering Society (AES) 138th Convention*

Neimeyer, R., 2009. *Constructivist Psychotherapy*. London: Routledge.

Newzoo, 2020. Key Numbers. [online] Newzoo. Available at: <https://newzoo.com/key-numbers/>

OFCOM, 2020. *Further Consultation: Making On-Demand Services Accessible*. [online] OFCOM. Available at: <https://www.ofcom.org.uk/__data/assets/pdf_file/0036/197856/further-consultation-making-on-demand-services-accessible.pdf>

Oleksik, G. and Brown, L., 2018. Sonic gems: exploring the potential of audio recording as a form of sentimental memory capture. In: *British HCI Group Annual Conference on HCI 2008: People and Computers XXII: Culture, Creativity, Interaction - Volume 1, BCS HCI 2008*. [online] Liverpool, UK: British HCI Group. Available at: <https://www.researchgate.net/publication/221436882_Sonic_gems_exploring_the_potential_of_audio_recording_as_a_form_of_sentimental_memory_capture>

Polychronopoulos, S., Kougias, D., Polykarpou, P. and Skarlatos, D., 2013. The Use of Resonators in Ancient Greek Theatres. *Acta Acustica united with Acustica*, 99(1), pp.64-69.

Specialeffect.org.uk. 2020. *Helping People With Disabilities To Enjoy Video Games | Specialeffect*. [online] Available at: <https://www.specialeffect.org.uk/>

Stegers, R. and Baumann, D., 2010. *Sacred Buildings*. Basel: Birkhäuser.

The Royal National Institute for Deaf People, 2020. *Facts And Figures*. [online] RNID. Available at: <https://rnid.org.uk/2020/11/old-name-new-purpose-action-on-hearing-loss-becomes-rnid-again/>

Traer, J. and McDermott, J., 2016. Statistics of natural reverberation enable perceptual separation of sound and space. *Proceedings of the National Academy of Sciences*, 113(48), pp.E7856-E7865.

Tzanetakis, G. and Cook, P., 2000. MARSYAS: a framework for audio analysis. *Organised Sound*, 4(3), pp.169-175.

UKIE, 2020. *UKIE Annual Review 2020*. [online] UKIE. Available at: <https://ukie.org.uk/resources/ukie-annual-review-2020>

Van Tol, R. and Huiberts, S., 2008. *IEZA: A Framework For Game Audio*. [ebook] Gamasutra. Available at: <https://www.researchgate.net/publication/255968315_IEZA_A_Framework_For_Game_Audio> [Accessed 16 November 2020].

World Health Organisation, 2020. *Blindness And Vision Impairment*. [online] World Health Organisation. Available at: <https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment>

Appendix

Reverberation from Memory Study raw results

Survey results can be found hosted at https://lukesaudio.com/elicitationsurvey.htm

Triadic Elicitation Pilot Study raw results

The pilot study raw text can be found at https://lukesaudio.com/triadicresults.txt