XR accessibility insights and toolkit: gaming sector report

Authors:
Abertay University, Dundee
Dr Lynsay Shepherd, Reader in Cybersecurity and Human-Computer Interaction
Dr Hailey Austin, Lecturer in Visual Media and Culture
Dr William Kavanagh, Lecturer in Games Technology and Mathematics
Dr Naman Merchant, Lecturer in Games Technology and Mathematics

Commissioned by the Royal National Institute of Blind People

Actionable insights

Key design principles for creating accessible XR experiences:

- Always evaluate experiences with blind and partially sighted people.
- Accessibility should be built into the on-boarding phase.
- Reflect on the use of seated or static standing XR experiences.
- Avoid relying on visual cues alone.
- Use audio design to enhance spatial awareness.
- Integrate touch-based feedback as an additional tactile response mechanism.
- Support customisation of audio, text, contrast, and input mechanisms.
- Keep interfaces clean and avoid cognitive overload.
- Game engine creators should consider creating improved accessibility tooling to support development of XR experiences.

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Introduction

The use of extended reality (XR) game technologies is on the rise, creating increasingly immersive experiences. However, limited consideration of inclusive design in this context often renders these experiences inaccessible for blind and partially sighted individuals. XR technologies encompasses virtual reality (VR), mixed reality (MR), and augmented reality (AR) experiences, all of which can be developed using game technologies.

This report was commissioned by the Royal National Institute of Blind People (RNIB) and created by an interdisciplinary team based in the Faculty of Design, Informatics and Business at Abertay University, Dundee, United Kingdom.

The aim of this report is to present actionable insights targeted towards the gaming industry to support development of accessible XR experiences. Thus, we begin by presenting an overview of cutting-edge research at the intersection of accessibility and games, with a particular focus on sight loss and XR experiences. We then present our findings derived from interviews with professional game developers with a variety of experience with accessible design.

Building on existing research and consultations with practitioners, we applied these findings and augmented a VR prototype, Rhizoma VR, with features to improve accessibility for blind and partially sighted people (BPS). Rhizoma VR was then evaluated by a group of people with varying levels of sight loss, to evaluate the efficacy of the augmentations integrated. Evaluation results allowed us to corroborate our actionable insights for the games industry, supporting future development of accessible XR experiences.

Gaming offers a powerful means for individuals to feel included in a community, positively impacting mental health and reducing social isolation. Therefore, it is imperative that XR gaming experiences are accessible to a wide audience, especially for those who are blind and partially sighted. The games industry has a clear opportunity to support this through inclusive design practices, and we hope this report provides a basis to facilitate the development of accessible XR experiences.

Executive summary

Key recommendations from existing studies

- **Binaural and spatial audio**: this can be used to help interpret placement of in-experience assets, or to support navigation (through echolocation), and increase immersion. The use of beeps for navigation may be considered irritating.
- **360-degree video and spatial audio:** blind and partially sighted participants showed a greater sensitivity to mechanical sounds, suggesting their auditory perception plays a crucial role in their immersive experience.
- **Voice cues:** these can aid navigation by enhancing object orientation and distance perception.
- **Touch-based feedback:** this can include the use of haptic gloves, tactile displays, vibrotactile or force feedback to provide additional mechanisms for user feedback, reducing the need to rely on visuals.
- **Accessibility options**: customisation is vital for blind and partially sighted people, for example, having the ability to adjust magnification, brightness, contrast, edge enhancement, peripheral remapping, text augmentation, text to speech and depth (adjusting the focal length).
- **Testing with blind and partially sighted people:** all too often, studies did not utilise or recruit participants with vision impairments. It is crucial to test experiences with those who have lived experience.

Key recommendations from the practitioner consultation

- **Consult existing materials:** developers should seek to consult the wealth of accessibility materials available online to support development, for example, the Game Accessibility Guidelines, Xbox Accessibility Guidelines, the W3C's XR Accessibility User Requirements, and work conducted by Special Effect.
- **Multi-modal communication:** reduce the reliance on visuals for communication and carefully consider sound design and audio feedback. Additionally, consider the use of haptics for additional feedback (such as the haptics used in PlayStation VR2 in the controllers and the headset itself).
- **Customisable accessibility settings:** include a variety of built-in options to support players with diverse needs and multiple

disabilities, for example, adjustable text size, and different contrast modes.

- **A need for better accessibility tools:** the games industry needs to work together to produce more effective accessibility tools, for example, better physics-based audio simulation, improved aesthetics of accessible visuals, artificial intelligence (AI) tools which do not need to run locally.
- **Address toxicity against accessibility initiatives:** Prioritise educating the broader community on the benefits of inclusive design, dismissing baseless criticisms of features that enhance accessibility without affecting the gameplay of others.
- **Testing:** test early and test often with blind and partially sighted people; using blindfolded sighted individuals is not an appropriate substitute.

Key recommendations from the Rhizoma VR user study

- **Screen reader compatibility:** if a game has a built-in screen reader, ensure it does not conflict with the system screen reader.
- **Accessibility settings:** ensure games have a range of accessibility settings built-in to cater to a range of needs. Such features should be tested with those who have lived experience to ensure they perform optimally.
- **Contrast:** provide different contrast options and in-experience highlighting to help people navigate dark or low contrast environments. Some high contrast options (such as inverted colours, for example black text on a bright white background) should come with a photosensitivity warning.
- **Text size:** scalable user interfaces are vital, as oftentimes, a small font size is used throughout game environments. Similarly, in XR and 3D environments, the focal length should be adjustable to bring the text closer, or to move it further away from the user as needed.
- **XR experience types:** seated or static standing experiences are preferable, reducing the risk of collision with obstacles.
- **XR headsets:** where possible, make XR experiences cater to a range of headsets - some users feel certain headsets are heavy; this would allow them to choose the most comfortable headset for them.

- **Menu voice options:** voiceover should sound natural, particularly if AI voices are implemented.
- **Menu navigation and control:** head-based gestures can be effective forms of menu navigation. Alternative modes of control should be provided for users with physical limitations such as issues with head and neck movements.
- **In-game navigation:** ensure waypoints or a horizon is implemented in games to support navigation.
- **Sound design:** to enhance the experience, audio indicators could be used to convey movement, along with audible objects in the environment.

Future work

The responsibility for addressing accessibility in XR experiences should not fall only on blind and partially sighted people. Thus, this toolkit offers guidelines designed to support the games industry in creating more inclusive experiences going forwards. Gaming and XR experiences offer a myriad of benefits from reducing social isolation, to improved mental health, therefore it is important these experiences are as inclusive as possible. This requires input from people with lived-experience, developers, platforms, specialist charities, policymakers, and academia; by working together, we can achieve this goal.

1 Introduction

Vision impairment can be defined as “any functional limitation of human vision that cannot be corrected by means of corrective glasses or contact lenses” (Agrimi et al., 2024). The term vision impairment encompasses all degrees of loss of vision, including low vision and blindness, that affect a person’s ability to perform daily life tasks (Bailey and Hall 1990). Videogames have often been inaccessible to gamers with disabilities, and particularly to people with vision impairments (PVI[1]) (Bierre et al., 2005; RNIB 2022; Yuan 2009). Barriers can exist for PVI to access specific games due to their inaccessible design (Bolesnikov et al., 2022), often because these games were not initially designed with PVI in mind (Thevin et al., 2021). As an example, level design – defined as “the practice of planning and building spaces for video games” (Level Design Book, 2025) - relies heavily on visual direction to convey information or emotions using light, symbols, patterns, color theory, contrast, scale, negative space, and camera framing (Kremers 2009; Totten 2019). PVI, however, tend to rely on touch and hearing to generate a reliable mental image of their environment (Cattaneo and Vecchi 2011). In this sense, videogames, as a medium, industry and as critical objects, fall into what disability theorist David Bolt defines as “ocularnormativism”: that is, “the mass of institutionalized endorsement of visual necessity” and “the conclusion that the supreme means of perception is necessarily visual” (Bolt 2013, 5 and 14; qtd in Campana 2022, 169).

The concept of normativism was defined by Rosemarie Garland-Thomson (1997) as “the constructed identity of those who, by the way of bodily configurations and cultural capital they assume, can step into a position of authority and wield the power it grants them”. In other words, this is the culturally constructed idea of a “normal” body. There is a distinct friction between the normate game design which prioritises the experience and needs of

[1] Please note, the terminology used in this section switches between people with vision impairments (PVI) or blind and partially sighted people (BPS), or simply just because “blind” is the terminology used in literature we are referencing.

normate players, and the reliance on ocularnormativism and accessibility in games for non-normate players.

Accessibility functions in games have previously been seen as an afterthought or post-release update rather than embedded in the design of the game itself. This is because discussions of game accessibility are usually limited to accommodations added to the game by non-disabled developers where the game assumed nondisabled players as the default (Campana, 2022, 165). However, in recent times, increased attention has been given towards games that are accessible to people with vision impairments. Major video game companies such as Electronic Arts (EA) have released a draft of their accessibility patents for free, supporting game developers in their goal of inclusive gaming (Electronic Arts, 2025), whereas Microsoft have launched an Inclusive Design Toolkit (Microsoft, 2025), which spans their product portfolio, and targets a wide range of needs and perspectives. As part of their Xbox Game Studios and Turn 10 companies, Microsoft worked with PVI as partners during the development of Forza Motorsport to enhance accessibility for blind and low-vision players through Blind Driving Assists (Xbox, 2023). The inclusion of accessibility in games has been further bolstered though the growing advocacy and awards from the International Game Developers Association (IGDA) Accessibility Special Interest Group (SIG) and their flagship #GAConf (Games Accessibility Conference) events (#GAconf, 2025).

In games studies, videogames have been heralded as embodiment tools where players assume the identity of the main character and make choices through “projected identity” (Gee, 2008) as a form of “identity tourism” (Nakamura, 2002, xv). Their interactive nature allows for perspective-taking, which combined with embodiment can increase empathy development (Li and van Berlo 2025). This intersects with disability studies in which there has been a call for the development of “a theory of complex embodiment that values disability as a form of human variation” (Siebers, 2013, 284). However, in disability studies there are argument for and against disability simulation “because they offer a view of complex embodiment that enlarges standpoint theory” in that they fail to give the full sense of embodied knowledge held by disabled people (ibid., 286). In fact, it has been shown that disability simulations fail because they place people “in a time-one position of disability, before knowledge about disability is acquired usually resulting in emotions of loss, shock and pity at how dreadful it is to be disabled" (Siebers, 2013, 286). In a disability studies humanities listserv, Catherine Kudlick - Director of the Paul K. Longmore Institute on Disability in San Francisco - argued:

> "Rather than blindfolding students for a hour, then, it is preferable to send them off wearing sunglasses and carrying a white cane, in the company of a friend, to restaurants and department stores, where they may observe first-hand the spectacle of discrimination against blind people as passersby avoid and gawk at them, clerks refuse to wait on them or condescend to ask the friend what the student is looking for, and waiters request, usually at the top of their lungs and very slowly (since blind people must also be deaf and cognitively disabled), what the student would like to eat" (qtd in Siebers, 2013, 286-287).

1.1 Research questions

Several questions guided our approach when considering existing literature and synthesising these studies:

- What existing games have been adapted to be more accessible to people with vision impairments?
- What studies have been done into virtual reality, augmented reality, and/or extended reality games with people with vision impairments?
- What key takeaways from these studies could be implemented into future XR games to make them more accessible and enjoyable for people with vision impairments?

1.2 Methodology

Keywords were input into Google Scholar and Abertay University Library. Initial results were read and analysed. Following this, relevant cited papers were also read and evaluated.
Keywords included:

- Blind, partially sighted, visual impairment
- Immersive, immersion
- Game, videogame
- Virtual Reality, Augmented Reality, Extended Reality
- VR, AR, XR

- Accessibility

1.3 Results

1.3.1 Making existing games more immersive and accessible

There is ample academic literature on innovative software and hardware developed to make games more accessible to PVI (Agrimi et al., 2024). Gibbons finds that the majority of “research approaches to disability and games often consist of studies of the efficacy of using games to achieve therapeutic outcomes” (Gibbons, 2015, 25). These often focus on adapting existing games for PVI. These can be split into AR and VR adaptations.

1.3.1.1 AR

Augmented Reality adaptations to games include sonic badminton, aimed at allowing people with and without vision impairments to play badminton together (Kim, Lee and Nam, 2016). In Kim, Lee and Nam’s 2016 study, they created racquets augmented with a wireless sensor and used virtual shuttlecocks which were represented through localised binaural audio output. The players had to interpret the sound and swing accordingly. Similarly, Blind Hero is an adaptation of rhythm-based game Guitar Hero with a custom glove for haptic feedback (Yuan and Folmer, 2008). Eyes-Free Yoga utilised Microsoft Kinect to track player poses and provide audible instruction to feedback to players (Rector et.al, 2013).

Another study incorporated adaptations of puzzle games like sudoku incorporating tangible haptic displays connected to a computer that communicated game information to the player via touch (Gutschmidt et al., 2010). In Gutschmidt et al.’s 2010 study, they created customisable and tactile displays with rows of dots to communicate sudoku numbers. In these examples, a large emphasis was placed on both audio and haptic feedback to adapt existing games.

1.3.1.2 VR

Virtual Reality has also been used to adapt games and make them more accessible to people with vision impairments. Virtual Showdown is a digital adaptation of Showdown a live game where people wear blindfolds and use their hearing to locate and hit a ball into the goal of their opponent (Wedoff et al., 2019). Virtual Showdown combined 3D audio design with Microsoft Kinect version 2, Nintendo Switch joy-cons with haptic feedback, cardboard and a table. They tested with 34 blind and partially sighted participants from age 8-20. The study aim was to determine whether participants preferred verbal instructions or verbal and haptic feedback instructions. While the preferences were mixed, participants scored higher with only verbal scaffolds. The authors believe this to be because the combination of verbal and vibration caused a higher cognitive load (Wedoff et al., 2019, 12).

Another study, SEEINGVR, created a set of 14 low vision tools that can augment a VR application using an overlay to give both visual and audio feedback (Zhao et al., 2019). With SEEINGVR, users can select, combine and adjust different tools based on their preferences and needs. There are 9 tools for VR augmentation that do not require the games developers to change any code including a magnifying glass, bifocal lens, brightness lens, contrast lens, edge enhancement, peripheral remapping, text augmentation, text to speech and depth measurement. SEEINGVR also includes tools that require developer input comprising of object recognition, highlighting, guidelines, recolouring, and the implementation of additional assistive apps in VR such as AR and smartphone implementation. Additionally, the toolkit includes Wizard of Oz voice commands for tool selection.

The SEEINGVR study recruited 12 participants, 6 of which were low vision with a mix of vision impairments. The low vision participants and sighted developers were asked how they would prefer to control the tools. All participants with low vision wanted to adjust the tools in-situ via a shortcut command (such as a voice command or button on the controller).

1.3.2 Creation of new games or experiences

Other studies focus on the creation of hardware to gamify or make spaces more accessible to PVI through AR, VR, and MR such as exer-games (India et al., 2021), virtual canes (Kunz et al., 2018; Maidenbaum et al., 2013), haptic gloves (Gonzalez Penuela et al., 2022; Tzovaras et al., 2009), head mounted displays (Maidenbaum et al., 2016; Adrade et al., 2022; Zhao et al., 2015;

Thevin et al., 2020) and spatial cognition belts (Riviere, Gay and Pissaloux, 2018; Romeo et. al 2023), and mixed reality applications (May et al., 2020).

1.3.2.1 AR

VStroll is an audio-based exercising game (exer-game) for mobile devices that allows PVI to explore a real-world location virtually from their homes in order to build a mental map of the explored environment and get exercise (India et al., 2021). The user puts their phone in their pocket and walks in place to navigate real world locations and can discover places of interest. Spatial audio, binaural audio and voice input is used to signal points of interest, fitness and trip announcements for route selection. All 16 participants in the study were blind (India et al., 2021). Twelve of the sixteen participants found the app to be highly immersive because the points of interest, fitness and trip announcements took participants attention away from the monotony of walking and encouraged virtual exploration (India et al., 2021). VStroll increased participants’ spatial knowledge, enabled free exploration of real-world locations, and motivated the participants to walk more even after the study ended (India et al., 2021).

ForeSee is a customisable head-mounted vision enhancement system for people with low vision (Zhao et al., 2015). It has five enhancement methods: magnification, contrast enhancement, edge enhancement, black/white reversal, and text extraction which can be customised to fit different users’ needs, with both full display and window modes. Foresee is considered augmented reality because it consists of an embedded processor, a camera and a display that rests over the users’ eyes to augment their surroundings. The camera captures the user’s view, the processor enhances the captured video feed, and the display presents the enhanced video feed to the user. The study was conducted with 19 low vision participants with a variety of visual abilities and an Oculus. They were asked to complete two visual tasks: reading a page of printed text and reading and describing textual signs that were hung at eye-level 3 meters away. Most participants (15 out of 19) felt that they were able to improve their visual experience by combining enhancement methods, and all preferences differed in the two tasks. Foresee was helpful for people with a wide range of vision abilities but was not suitable for those with too little functional vision or people with too much vision. There were processing delays which negatively impacted participants attitudes towards Forsee. It was suggested to use smaller, lighter and more suitable hardware for head mounted systems.

1.3.2.2 VR

Echolocation has been suggested as a useful interaction approach that enables people with vision impairments to access virtual environments by creating mental maps of the environment. Andrade et al.'s 2022 study used a participatory design approach and the creation of two VR game prototypes co-developed with blind and partially sighted people and echolocation experts (Andrade et al., 2022). The study recruited 3 blind and partially sighted participants with a range of low to no vision who were echolocation experts and had interacted with an echolocation-enabled virtual environment before. The prototypes took into consideration the importance of passive echolocation and included ventilation fans as an ambient sound, alongside the use of landmarks and compass directions. The participant's preferred echolocating sound was imported into the prototype (e.g., a mouth clicking sound, a finger snapping sound, and environmental sounds) as these were navigation tools they had been using for a number of years. Ultimately the evaluation highlighted that echolocation can be successfully implemented in a virtual environment and offers the opportunity to support blind and partially sighted people in the creation of a mental map.

1.3.2.2.1 Virtual canes

Virtual canes were a common hardware created to help BPS navigate, often with force feedback or through simulated environments.

HOMERE is a VR system when the user wears an Oculus head mounted display and utilises a cane that is triggered by force-feedback (Kunz et al., 2018). This combined with audio and thermal feedback allows the user to navigate a 3D space and build a mental map of their surroundings. However, the initial tests showed a high number of collisions and long periods of not walking but stopping for acoustic orientation. Critically, this was not tested with people with vision impairments, only with blindfolded participants.

Similarly, the Virtual EyeCane is a virtual mobility aide that can be used in any virtual environment to improve accessibility to VR spaces (Maidenbaum et al., 2013). The EyeCane attempts to augment the classic white cane using sensors to detect obstacles from five meters away and transmits this information through a simple auditory cue, such as a beep. The virtual EyeCane aims to do this in virtual spaces, enabling users to navigate virtual spaces. The participants navigated an online space seated in chair and responded to different noises as they attempted to navigate the 3D virtual space and avoid collisions. There were 23 participants in the feasibility study, 3 were congenitally blind. The 20 sighted participants were blindfolded for the study. Both sighted and blind and partially sighted participants were able to complete the levels in the allotted times.

This informed a larger study of the physical EyeCane created by Amedi and Hanassy 2012, that uses infra-red sensors aimed in different directions with tactile and audio outputs (Maidenbaum et al., 2014). The larger study had 38 sighted blindfolded participants, and 5 visually impaired participants. The study asked participants to estimate the distance to different objects based on tactile feedback from the EyeCane, navigate unfamiliar natural environments, and avoid obstacles with less than 5 minutes of training. While the distance estimation was not successful, as participants randomly made-up distances, the EyeCane was shown to have a positive effect on navigation and obstacle avoidance with both sighted and blind and partially sighted participants.

1.3.2.2.2 Haptic Gloves

Tzovaras et al.’s 2009 study utilised the CyberGrasp, a haptic glove device that tracks human-hand movement inputs and is able to give haptic force-feedback. They developed a mixed reality cane simulation environment based on their Cane Simulation VR tool developed for the training of blind and partially sighted people (Tzovaras et al., 2004). The Mixed Reality interface in an extension of the VR cane simulation. The user wears the CyberGrasp and a waistcoat that carries the magnetic sensors. Sound and haptic feedback are provided by the system upon the collision of the cane with virtual objects. Environmental sounds are assigned to static objects and dynamic objects in the virtual world. The initial studies were conducted with 26 blind and blind and partially sighted users (Tzovaras et al., 2009, 56). All participants were able to successfully complete the orientation tasks. The majority of the users preferred mixed reality with multimodal feedback, noting the importance of both acoustic and haptic feedback for orientation (Tzovaras et al., 2009, 57).

Gonzalez Penuela et al.'s 2022 Hand-on study designed a set of hand gestures that can be performed in VR to request descriptions about the virtual environment. In order to detect the gestures, they designed a haptic glove that measures the extension and position of the user's fingers and hand and that can give force feedback to complement the audio feedback (Gonzalex Penuela et al., 2022). The idea of the haptic glove and hand gestures is to make VR more holistic and accessible to BPS. A user study has not yet been conducted.

1.3.2.2.3 Head mounted displays

SSD EyeMusic is a Sensory Substitution Device for blind people in VR environments which converts visual image characteristics into different sound instruments to conduct different tasks (Maidenbaum et al., 2016). Visual to audio sensory substitution devices can increase accessibility by sounding on-screen content. The EyeMusic SSD was created to give whole scene visual information via audio descriptions and feedback in virtual environments. EyeMusic was tested with 8 congenitally blind users and 19 sighted-blindfolded participants who had to navigate virtual environments and find doors, differentiate between them and walk through them. These tasks were accomplished between 95-97% success rate with the blind users who also reported feeling immersed in the environment.

X-road is an affordable and accessible VR system for Orientation and Mobility classes for people with vision impairments (Thevin et al., 2020). Using a smartphone and a bespoke headmount, X-Road provides visual and audio feedback that allows users to move in space virtually as in the real world. Using the AR framework ARCore which allows users to move around a virtual object positioned in the real world. In this system, it was used to create a virtual street and crossroad in a 1-2-1 scale. The study was conducted with 13 students with vision impairments (a combination of low and no vision) and was shown to be effective in teaching orientation and mobility. X-Road consists of VR goggles which consist of a smartphone and 3D-printed DIY support and headphones for audio feedback. These were chosen over HMD goggles which are heavy and cause physical discomfort. The majority of the tasks had a success rate from 82-100%. While the X-road was seen as comfortable, many participants did not like the synthetic engine sound and wanted basic audio features with different types of feedback like in real life.

1.3.2.2.4 Spatial Belts

The Tactibelt is a device that interfaces with the user through a belt with 3 levels of vibrators worn around the waist (Rivière, Gay and Pissaloux, 2018). The device also includes 2 front-facing cameras embedded into a pair of glasses combined with an inertial unit to provide stable orientation-aware depth information about nearby obstacles. A GPS chip provides localisation and distance information for nearby landmarks. It provides 4 types of information: nearby obstacles, landmarks, topography including street intersection nodes and current destination. All 4 types have a different vibration representation to distinguish between them.

The Tactibelt was used in a later study and paired with a force-feedback tablet with a graphical interface dedicated to haptic environment development (Romeo et al., 2022). The tablet could simulate elevation feedback and friction feedback with different textures. The Tactibelt can be used in both real and virtual environments. This experiment involved seven blindfolded participants navigating a virtual world seated using the Tactibelt (Romeo et al., 2022).

A 2023 study used virtual reality as a platform for testing, refining and training with electronic travel aids (Ricci et al., 2023). The study tested the viability of an in-house wearable haptic feedback device design. This first phase of testing was with 48 sighted participants with simulated vision impairments. The users wore the haptic device and performed virtual tasks while experiencing a simulation of one of three different vision impairments: age-related macular degeneration, diabetic retinopathy, and glaucoma. The study found that the combination of VR and electronic travel aid reduced the number of collisions for diabetic retinopathy and glaucoma, and improved completion time for all three vision impairments. The impairments were created with a combination of two different tools in Unity for an Oculus Rift headset with Oculus Touch motion controllers.

1.3.2.3 Mixed Reality

In 2020 a study was done on mixed reality (the combination of VR and AR), exploring soundscape and spotlight designs for interior navigation and ad-hoc cognitive map formation in people with vision impairments (May et al., 2020). First, participants explored a virtual soundscape in room-scale VR. There were five participants in the first study all of whom were blind or had low vision. The findings from the first study led to rapid prototyping of a Mixed Reality (MR) version of the system which was user tested in a real building using a mobile device. The second study had five participants, including two from the first study, all of whom were legally blind. In the second study, bone conducting headphones and an iPhone 8 running Unity software for the soundscape were used. The Unity prototype was adapted from the VR version from the first experiment to become a mixed reality iOS app with real-world tracking using the mixed reality toolkit ARKit.

1.3.2.4 Considerations

The above studies highlight some of the research being conducted into making games more accessible to blind and partially sighted people. These studies highlight the growing potential of bringing games into AR/VR so that people with vision impairments can play them as well as the use of AR/VR tools to aid in orientation in both the virtual and real worlds.

Many of these studies have not utilised participants with lived experience of vision impairments. For example, Kunz's 2018 study used sighted users who were blindfolded to test their virtual cane. Yuan and Folmer's 2008 study used a mix of blind, blindfolded and sighted participants. Riviere, Gay and Pissalou's (2018) Tactibelt mobility assistive device study was not tested with blind and partially sighted users at all and the follow up study by Ricci et al., 2023 only simulated vision impairments with sighted users.

1.3.3 User preferences

In tests with headphones and multiple interfaces, such as separate noises going into the left and right ear) and different beeps for collision, users were irritated by the different kinds of beeps at different paces in each ear (Kunz et al., 2018). This study, however, was not conducted with blind and partially sighted users.

The studies that did utilise people with vision impairments found that because of the wide variety of vision impairments, customisation of the inputs and feedback were key to enjoyment and immersion (Zhao et al., 2015; May et al., 2020).

They also found that when using audio feedback, cognitive load of the player needs to be taken into consideration (May et al., 2020; Zhao, 2024). In May et al.,'s 2020 study participants preferred the use of realistic Auditive Icons, descriptions via TTS or a mix of both, providing a more complete description. Limiting the sound experience to only sounds present in the same location as the user helped them not feel cognitive overload. Adding redundancy and explicit representation for information made things clearer for the user. Users often preferred to choose between TTS voices and genders (May et al., 2020).

The SEEINGVR study recruited 12 participants, 6 of which were low vision with a mix of vision impairments (Zhao et al., 2019). The low vision participants and sighted developers were asked how they would prefer to control the tools. All participants with low vision wanted to adjust the tools in context via a shortcut command (such as a voice command or button on the controller) rather than the voice control.

1.4 Conclusions and recommendations

The majority of work done with AR/VR for blind and partially sighted users focuses on both audio and haptic feedback. VR can be made more immersive for PVI, provided the necessary audio and haptic cues are in place and the design combines the interactions that are exclusive to VR with existing PVI skills (Júnior, Viana, Façanha, 2024). The most common feedback implemented in AR and VR is audio (spatial or binaural) or touch (haptic, tactile, vibrotactile or force feedback), while the use of TTS, gestures, motion sensors, customization features, tips system and in-game analytics can make for more robust solutions for users (Júnior, Viana, Façanha, 2024). This has to be balanced with the possibility for cognitive overload from too many inputs (Zhao, 2024; May et al., 2020).

There were some studies creating AR/VR solutions for blind and partially sighted people that did not utilise or recruit participants with vision impairments. Using blindfolded sighted participants instead of individuals who have lived-experience of vision impairment is not an appropriate approach.

The majority of studies that utilised people with vision impairments found that because of the wide variety of vision impairments, customisation of the inputs and feedback were key (Zhao et al., 2015).

In MR, some studies looked into the optimisation of both VR and AR environments with a focus on not overloading the listener but to still improve the process of creating cognitive maps (May et al., 2020). In tests with headphones and multiple interfaces (separate noises to left and right ear, different types of beeps for collision) users who were not blind and partially sighted were irritated by the different kinds of beeps, and found it difficult to interpret beep pace between left and right ear as well as head movement (Kunz, et al., 2018).

Thus, these findings and recommendations inform the design and augmentations implemented into the Rhizoma VR experience described in section 3.

2 Practitioner consultation

2.1 Introduction

This section details the findings of consultations with professional game developers. Five individuals were interviewed across a diverse range of expertise, roles and companies. Structured conversations were used where each participant was prompted from the same set of questions.

2.2 Research questions

As part of this we wanted to directly answer some key questions about the process of developing accessible XR experiences for people with vision impairments (PVI[2]). Specifically, those were:

[2] The interviewer used people with vision impairments (PVI) as the terminology for blind and partially sighted people (BPS) in this section.

1. What established and emerging practices are employed by practitioners to enhance game accessibility?
2. What are the key challenges and practical considerations encountered by practitioners when developing and implementing accessible games?
3. How are the needs and perspectives of PVI incorporated into game design, development and evaluation?

While these motivated the content of the consultations, insights were also sought on attitudes on XR use and accessibility from both developers and players, opportunities for professional development and resources for upskilling and on the impact of accessible game development.

2.3 Methodology

2.3.1 Process

A structured interview was carried out with five practitioners. All interviews were conducted remotely, recorded and later transcribed. Questions were consistent between interviews and shared in advance. Interviews ranged in length from 30 minutes to 90 minutes. Participants all consented to being on-the-record.

2.3.2 Practitioners consulted

- Cari Watterton, Senior Accessibility Designer at Rebellion Games
- Jamie Bankhead, CEO of Konglomerate Games
- Katie Goode, CEO of Triangular Pixels
- Sam Watts, Senior Partner Relations Manager at Unity
- Sky Kim, Senior Engineer at Unity

2.3.3 Questions asked

To address the RQs, we asked each practitioner the following set of questions:

RQ	Question
1	• Can you describe some of the accessibility-focused practices you have been involved with at [your current company]? Particularly focused on accessibility for PVI.* • Are PVI involved in the development of new experiences?

	• Do you incorporate multi-sensory elements and how have you done so? • What techniques or tools have you found to be effective, and perhaps underutilised, in designing accessible experiences for PVI? • What technologies do you think will shape accessible design for PVI in the future? • Are there areas, methodologies or practices that particularly excite you?
2	• What are the challenges you face in designing for PVI? And are there any that you come across that you had not considered? • What level of vision impairment do you design for? • Were there any additional challenges faced in the XR experiences that you developed?
3	• How do you assess how accessible your experiences are? • Do PVI feature in that assessment? And if so, how is this organised? • Are PVI involved in the development of new experiences?
Additional	• What are the attitudes towards XR development at [your current company]? • Is XR likely to feature significantly in upcoming projects? * • What form of training or knowledge exchange do [your current company] have for accessibility?

* Note: Some participants were not able to answer on the record about upcoming projects.

2.3.4 Qualitative analysis

Transcribed interview data was analysed using a thematic analysis approach. Each transcript was systematically reviewed to identify portions that were relevant to the research questions. Typically, these were responses to specific questions in-line with the table above. Key concepts and statements were grouped together to identify themes, patterns, contrasts and examples which have been brought together as ‘themes’ in addressing the research questions.

2.4 Results

2.4.1 RQ1: What established and emerging practices are employed by practitioners to enhance game accessibility?

2.4.1.1 Guidelines, documentation and legal requirements.

All practitioners noted that excellent material on general guidelines and best practices for game accessibility is available. Katie Goode was a contributor to the Game Accessibility Guidelines (2012), a publicly available resource that supplies graduated levels of accessibility features. Cari Watterton highlighted the Xbox Accessibility Guidelines (Microsoft, 2023), produced by Microsoft, alongside the Game Accessibility Guidelines, as areas where they begin to "help guide us and steer us on the right path" when it comes to making games accessible. Jamie Bankhead talked about the internal wiki that they keep which "has resources on accessibility and best practices that pulls from a lot of guide and toolkits like Microsoft's, Special Effect's (2025) [an accessible gaming charity] and the recent RNIB toolkit. We also try and check in on things like the Can I play That? Database [(Can I Play That?, 2025)] for new techniques".

Sam Watts highlighted the accessibility packages now part of the Unity game engine: "Unity has accessibility packages which developers can incorporate to make their games more accessible, which are studied, reviewed and improved over time". Sky Kim described the effect of these new packages: "Following Unity's official release of its accessibility package last year, several third-party developers have already begun creating open-source accessibility solutions."

On keeping up with the emerging practices everyone highlighted the role of actively researching current state-of-the-art through databases such as Can I Play That? As well as industry events, like GDC, Develop, and GAConf, and through academic work, including the XR Foundations XR For All programme (XR Association, 2025).

Another key consideration are legal requirements for accessible systems, as mentioned by Sam Watts on previous work on serious games and exhibitions with games technology: "We had to take accessible design into consideration from the get-go, because of either legal compliance, or the fact we wanted to ensure that as many people could experience it as possible.”

2.4.1.2 Non-visual communication

Intuitively, when designing for PVI, it is important to consider audio design and other sources for multi-sensory feedback. PVI tend to rely on audio cues far more frequently than fully sighted players. Cari Watterton described the benefits of using audio feedback for in-game events in being “a really easy way to provide accessibility” while also making for “a more full and complete kind of soundscape”. Cari went on to emphasise the importance of providing audio feedback for all key actions in the game, such as picking up objects beyond just voice acting and text. The theme of effective holistic design being accessible recurred across many interviews.

Where possible, the advice on audio design was to provide a significant amount of stimulus and allow users to scale back if it was overwhelming. VR is spatial by nature, and spatial audio, where audio is presented in three dimensions, is part of that. Sam Watts described the immersive effect of this spatial audio where a fully blind player of an underwater experience could “still appreciate that he was underwater and sense the smaller and bigger fish”.

Beyond audio, an effective multi-sensory tool for accessible VR development is haptics; the sense of touch, usually stimulated through vibrations in a hand-held device like a controller. Sky Kim discussed their process utilising multi-sensory elements to create universally accessible experiences. As with others, they described how this approach “not only enhances accessibility but also delivers a richer and more intuitive experience”. The principle followed here is one of redundancy, that all messages can be delivered to the player regardless of a sensory deficit.

2.4.1.3 Designing for readability

As with providing more audio stimulus than one might expect and allowing users to scale back, a general emphasis was placed on ensuring players can adapt games to their needs. Jamie Bankhead described accessibility features that “seem really obvious” as elements that have been missed from other games. These included the option to change colours and fonts, and having a high-contrast mode. Sam Watts repeated this call for UI elements and font to be large and clear.

Simple practical advice from Jamie included checking the readability of text by trying to interpret it from across the room. When testing, consider what the UI elements look like under various lighting conditions and against different backgrounds.

Sky Kim highlighting difficulty with menu navigation in XR. An example they gave of this difficulty is the pin-entry required for authentication on some headsets which can even lock devices on repeated failure. Where there are multiple levels to a more involved menu system it is easy for a user navigating by audio cues alone to get lost. This was something that we investigated as part of our user evaluation.

2.4.1.4 Applying technology for accessibility

Emergent technology that can enhance the accessibility of VR games is primarily improved multi-sensory feedback (as described earlier under non-visual communication). Cari Watterton is optimistic about the new haptics of the PlayStation VR controllers in providing haptic feedback to assist PVI. New headsets often come with specific hardware advances offering new features. One increasingly common capability of new headsets is for eye tracking, which may have meaningful practical implications for wider accessibility, but participants were unsure of its utility for PVI.

With an increased awareness of the importance of accessible design, game development platforms are broadening their toolsets for accessibility. Sky Kim described the Unity Accessibility packages “which developers can incorporate to make their games more accessible”, expanding to provide support for highly customisable menus. Sam Watts expanded on this to describe how the Unity game engine itself was being made more accessible following advances to the accessibility features that the engine offered for game designers.

A key emergent technology that will likely have significant utility in accessible XR development is the recent advance in generative AI and deep learning models. This will be discussed later, under its own heading.

2.4.2 RQ2: What are the key challenges and practical considerations encountered by practitioners when developing and implementing accessible games?

2.4.2.1 Technical constraints & limitations

Game development tools are “still not very good” when it comes to physics-based audio simulation, according to Katie Goode who signposted just that as a space where “if someone wants to put money somewhere into really making VR accessible, then making an amazing audio tool set would be really useful”. While Sky Kim did highlight updated development packages from Unity, leading to independent developers improving the accessibility of their games, they went on to say that accessibility does get a low priority from engine developers when considered in contrast to more profitable features.

Looking ahead, Sam Watts is excited about the ability for headsets to present elements at different depths, but this is “not going to be coming along anytime soon” as current hardware that can do this is “ridiculous, expensive and heavy”.

Katie Goode raised an interesting point on the aesthetics of accessibility options, saying that “they look rubbish”, with this being one of the main reasons they have not used any of the available accessibility packages at Triangular Pixels. Integrating them into their projects, then having to make them pretty and fit-in alongside their existing assets is more work than making their own solutions.

Modern headsets house the computers that run the experiences, but as a wearable device this usually means they must be small and lightweight, leaving little allowance for powerful computational hardware. Sky Kim described running AI models directly on a device as causing “notable performance drops and making the experience less immersive”. Meanwhile, cloud computing alternatives, where computation is done remotely and streamed to the device, are “very costly”.

The trade-off between affordable hardware and computational capabilities is notable. An elegant solution to this that Sam Watts describes is “graceful degradation” where content is designed to adapt to the functionality of the hardware upon which it is being run.

2.4.2.2 Intersection of multiple disabilities

An important practical consideration when designing for PVI is that vision impairment may intersect with other barriers, broadening the complexity of a player's needs. Cari Watterton talked about designing for the deafblind community, a particularly difficult challenge as the two primary forms of delivering feedback to players are curtailed. They admit that "there's a little bit more that needs to be done in terms of figuring out those kinds of things and other intersections of disabilities as well". A key practice to address these intersectional needs is investigation of multi-sensory approaches, like haptics.

Players have a diversity of needs, even amongst PVI there is a diverse range of impairments to consider, from complete blindness to varying degrees of low vision. Sky Kim highlighted understanding these as "one of the main challenges" they encounter when designing for PVI.

2.4.2.3 Budgets and timelines

Ideally, all experiences are tested thoroughly on end users throughout development, but "timelines and budgets are a thing to consider" as mentioned by Jamie Bankhead. Sam Watts stated that "testing is usually one of the things that is cut sooner rather than later in order to save money". Working with PVI and other groups that have specific accessibility requirements is likely to be more expensive.

An effective method of reaching target audiences with testing is to use consultants, but many participants described the cost of this, especially for small and independent studios, as being too high. Additional avenues for representative design include staff who have lived experience themselves who can centralise the perspectives of end-users. Jamie described carrying over learnings from previous projects in a centralised repository. Katie Goode described how testing at public events led to Triangular Pixels gathering interested members of the public who were enthusiastic to provide feedback on current and future projects. Katie further expressed the importance of testing in non-gaming spaces, suggesting public events like business events and careers fairs to get a more nuanced perspective.

Katie explained how the development of certain accessibility features is inherently expensive. For example, she explained that text-to-speech -- to provide voiceover options for menu buttons -- is very costly, especially when it needs to be localised to multiple languages. And a lack of accessibility features provided by game engines further increased costs as development time is required to build them in-house.

2.4.2.4 Public opinion and stigma

Cari Watterton described the public reception specifically to accessibility options in games they have worked on as being positive ("really nice to see", "really cool") but acknowledged "this is not the case for everyone". Game development is notoriously difficult, and expensive, and the realities can be generally misunderstood by the public. This misunderstanding manifests in various ways, from underestimating the effort required to encountering outright hostility.

One significant challenge stems from negative reactions within parts of the gaming community. Practitioners identify the presence of "poisonous" and "toxic" "vocal idiots" who actively criticise accessibility efforts online. This negativity is often rooted in "a game mentality of get good, particularly prevalent in communities surrounding difficult games". This can come in the form of complaints made about optional accessibility features which do not affect their own experience being criticised, which one practitioner described as a "false complaint". This resistance highlights a tension, where enabling more people to play can be seen by some as compromising a core, often exclusionary, aspect of certain gaming cultures.

Beyond overtly negative comments, misconceptions about game development itself from the public can be difficult to navigate for developers. Cari recalled how some players were disappointed when features they felt were easy to implement were not included in new releases. An example they gave was screen readers, which they described as being part of "the expectations gamers have" about what should be included in new releases, not realising "these are a big, big chunk of work". This leads to what they describe as "disparity between the expectation of what players think is possible versus what is actually able to be done". One strategy to mitigate this they advocate is open communication about what is not going to be included, to set expectations appropriately.

2.4.3 RQ3: How are the needs and perspectives of PVI incorporated into game design, development and evaluation?

2.4.3.1 Measuring with PVI

In terms of the process of accessible design, an emphasis was placed by all participants on testing with end users early and often. While established resources like the Game Accessibility Guidelines (2012) or Xbox Accessibility Guidelines (Microsoft, 2023) provide a valuable starting point when measuring the accessibility of an experience, the crucial step involves directly measuring with PVI. We were told that studios use consultants or player recruitment programs through specialist groups for playtest sessions. Jamie Bankhead explained that planning for this external testing, conducted either remotely or in clinical settings, is part of Konglomerate Games' standard process when working with partners.

This testing can take various forms depending on studio, budget, stakeholders, and project stage. Examples include initial interviews, codesign workshops or observed play and subsequent interview, as described by Cari Watterton. They noted a shift in their practice towards an informal, conversation-led process with consultants who provided feedback while playing. Similarly, Sky Kim described engaging relevant individuals, like a visually impaired YouTuber, for brief feedback on prototypes. And the developing relationships with specialist groups was repeated by both Sam Watts and Sky Kim who work with Blind Burners to get a deeper understanding of PVI's experiences.

Several participants highlighted attempts to imitate disability – e.g., by wearing a blindfold or removing glasses -- as ineffective practice that gives poor, unrepresentative results. This approach fails to accurately account for the way in which people with vision impairment perceive the world.

Cari Watterton acknowledges that starting out in designing accessible experiences can be daunting. They suggest a pragmatic approach where instead of trying to address every conceivable disability label, developers should "focus on barriers, not just disabilities”. This helps frame design and testing, concentrating on identifying and mitigating obstacles to play regardless of diagnosis. This practical focus can make the task more manageable and lead to more effective, targeted accessibility solutions.

2.4.3.2 Testing early

There is a strong emphasis on involving people with lived experience as soon as possible in the development cycle. Jamie Bankhead explained that they “think about accessibility from the start of the process”, incorporating testing with PVI at various stages of the pipeline. They noted that it is “harder to make changes later in development” so they start building with accessibility in mind from the start as “it saves a lot of problems”.

This early consideration comes about in various ways beyond just initial planning. Cari Watterton described conducting interviews about planned systems before development, testing “early prototypes” with consultants shortly before being first implemented. Similarly, Katie Goode noted aspects like the readability of their art style were “tuned super early” informed by research into potential audience struggles and supplemented by sending early builds to testers. For specific types of content, like training materials, Sam Watts mentioned that subject matter experts were involved "from the get-go” to ensure correctness and accessibility.

The core rationale for this early and ongoing engagement was echoed by Sky Kim, who stated that involving PVI “throughout the entire development process is essential” to ensure “authentic user needs are incorporated… avoiding significant changes later”.

2.4.3.3 Building developer understanding

Effectively incorporating the needs and perspectives of PVI requires ongoing learning and a conscious effort to build understanding into the development team. The practitioners described a range of resources and strategies for this. As described before, external guidelines and databases serve as a common starting point for many. Cari Watterton also described watching videos of blind gamers and blind and partially sighted streamers can help to “demystify” PVI’s experience. Attending talks and industry workshops at industrial events, and subscribing to newsletters, were other techniques mentioned for external learning.

Fostering internal knowledge is equally important. Rebellion, for instance, maintains a large internal knowledge base with user stories, links, references and breakdowns of relevant conference talks. Additionally, they run inclusive design workshops. Konglomerate Games has an internal wiki compiling resources from guides and toolkits.

Engine and tool providers play a role also. Unity, represented by Sam Watts and Sky Kim, provide accessibility packages, online and bespoke training options (including face-to-face sessions and project reviews), and has hosted events like accessibility forums to bring developers together. Resources like these help standardise approaches and lower the barrier of entry for developers using this tool. A topic Sam Watts was particularly excited about was the accessibility of game development tools themselves which demonstrate best practice in designing accessible UI.

2.4.4 Further insights

2.4.4.1 Future Innovation

The practitioners highlighted some emerging technologies that have the potential to significantly impact accessibility by providing richer sensory feedback and dynamic adaptation.

The first of these was eye tracking, which Sam Watts described as “wonderful in terms of being able to provide additional forms of input, improving hand tracking and accuracy of user input” and Jamie Bankhead said was “the coolest thing I can imagine [that] will help accessible design” because “if you’re able to tell exactly where someone is actually looking and engaging with your game, you can adjust so much to fit that.” Eye-tracking that informs user engagement could then inform systems to improve readability of certain areas and limit the processing required to render portions not currently looked at – a process known as foveated rendering, potentially improving performance on computationally constrained headsets. Jamie is particularly interested in applications of eye-tracking for those with macular degeneration where the experience could compensate for blind spots by tracking gaze.

Sam did however highlight that currently the devices that are capable of eye-tracking, such as the Quest Pro, HTC Vive Focus Vision and PSVR2 are potentially “priced out of an average person’s reach”.

The second innovation that practitioners were excited about is high-definition haptics. New hardware such as the PSVR2 controllers are being built with improved rumble capabilities that Cari Watterton sees as a “third sensory method to help give more feedback to players and help them engage with games”.

2.4.4.2 Artificial Intelligence

Artificial Intelligence (AI), particularly recent advancements in generative models and computer vision, emerged as a frequently discussed technology with significant potential implications for accessible VR gaming. Practitioners highlighted its potential to directly enhance player experience for PVI and its democratising effect on development itself, while acknowledging current challenges.

Sky Kim described a practical example where AI was leveraged to improve user experience where GPT-4 Vision was combined with text-to-speech to create a mobile app capable of environmental descriptions through a phone camera. Looking towards game applications, Jamie Bankhead suggested generative AI could be used for synthesised voice acting for games lacking spoken audio. Sky also described a hypothetical ‘AI companion’ that interpreted visual context in VR and used conversational voice input to help with navigation and comprehension in virtual spaces for PVI.

Beyond player experience, AI has begun to enhance the ability of developers to create accessible experiences. Game engines like Unity have begun integrating AI into development environments, with the Sentis runtime engine being capable of adding AI-based speech-text translations and vision post-processing in Unity. Sam Watts envisioned AI assisting developers with vision impairment through voice-command driven debugging and enabling complex instructions.

However, practitioners also identified significant hurdles. As described before, the computational requirement of running AI models paired with limited capacity of on-device hardware for a VR headset introduces performance-constraints. Katie Goode raised important ethical and practical concerns regarding AI models that generate “convincing falsehoods” and unresolved questions on copyright infringements as part of training data.

2.5 Conclusions and recommendations

This consultation reveals that XR practitioners actively employ established guidelines and community resources to ensure validity, but place the highest value on direct, early and continuous engagement with PVI to effectively navigate accessibility challenges. A helpful framing of accessible development is to focus on ‘barriers’ rather than broad disability labels (Table 1). Despite these efforts, significant hurdles exist, including the technical limitations of current XR hardware and development tools, resource constraints affecting both implementation and testing, the complexity of intersectional needs, and managing public perception of accessibility efforts.

Barrier	Suggested action
Developers unsure of how to implement accessibility features	Consult the general guidelines and best practices for game accessibility and attend relevant workshops.
Hardware limitations	Provide fallback controls or voice alternatives.
Lack of testing with blind and partially sighted users	Recruit blind and partially sighted participants as testers early in the development process via user panels and talk to specialist charities.
Overloaded audio cues	Prioritise and layer feedback clearly (e.g. left/right, foreground/background) and make use of spatial audio. Consider a multi-modal approach e.g., haptics for feedback.
Poor aesthetics of accessibility features.	Consider bespoke assets to improve the design of the accessibility features.

Table 1 – overview of barriers developers cited when creating accessible experiences.

To address the interconnected challenges of accessible VR game development for PVI, concerted action across the ecosystem is needed. Developers should prioritise the embedding of PVI engagement throughout the development cycle, moving beyond late-stage testing, while fostering internal knowledge sharing cultures and practices. Platform holders should lower the accessibility burden through enhanced built-in support, while improving the accessibility of the tools themselves. Further research is required, by advocacy and research groups, to tap-in to the potential of emergent technologies like eye-tracking and HD haptics, as well as best utilising AI, while being mindful of the practicalities (and ethical considerations) of employing them in development. Finally, structures are required to connect PVI communities with game developers to centralise lived experience in the development of truly accessible games.

3 Augmenting the prototype Rhizoma VR application

3.1 Overview

This section of the report describes the Rhizoma VR experience we used as the basis for integrating our findings from the literature and practitioners on how to improve accessibility. It outlines the technologies used in development, including game engines and hardware. Next, we discuss the augmentations designed to make the experience more accessible.

3.2 Rhizoma VR

The Rhizoma VR experience developed by Dr Naman Merchant, is one facet of a collaborative immersive multimedia installation curated by Dr Hadi Mehrpouya; this was exhibited at Dundee Botanical Gardens for two weeks in September 2024. The ethos behind the overarching installation was to allow visitors to explore “what is it to be human in an increasingly urbanised world and considers how we connect as humans and with the natural environment” (Mehrpouya et al., 2024).

The VR experience contains three distinct environments (Figure 1); the user initially finds themselves standing in the middle of a desert. As they proceed through the experience, a kelp forest emerges before them. Finally, they reach the end of the experience, enveloped in darkness and surrounded by hundreds of fireflies.

Figure 1 – Examples of the landscape from the Rhizoma VR experience (from top to bottom: the desert, the kelp forest, and the fireflies).

Each of these environments are placed within three concentric circles (Figure 2), meaning the user will reach these environments regardless of their direction of travel.

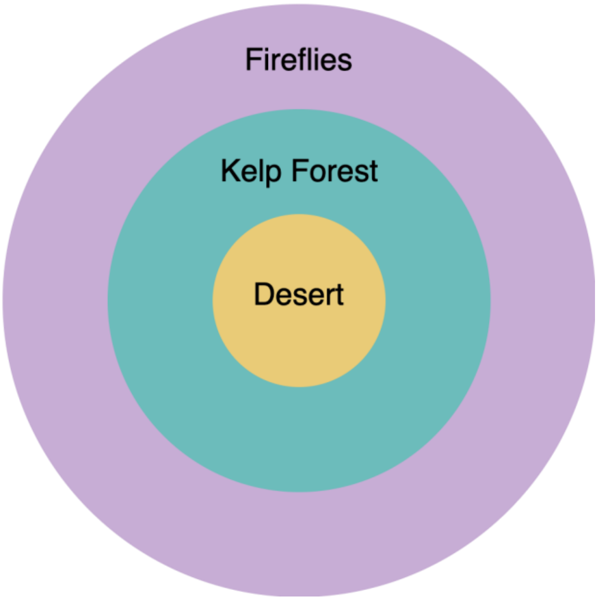

Figure 2 – representation of the three environments within Rhizoma VR.

Within the VR experience, users are free to explore. There is no designated path, and no controllers are required; users navigate by tilting their head forward to move and change direction.

3.3 Technologies used

Rhizoma VR was developed in Unreal Engine 5.3.2, a 3D computer graphics game engine (Epic Games, 2025) and made use of the OpenXR standard (Khronos Group, 2025), allowing the experience to run on a variety of VR headsets. The Rhizoma VR experience requires a controller PC or laptop containing an NVIDA GTX2080 graphics card (or better).

During the pilot study and user testing containing within this toolkit, we used a high-specification gaming laptop, which was a Medion ERAZER Beast X40 with 32GB RAM, a 17.3-inch display, an Intel Core i7 processors, and a high-end NVIDIA GeForce RTX 4080 graphics card as our controller device. A Meta Quest Pro headset (VR Compare, 2025) was connected to this via a USB C 3.0 cable.

3.4 Augmentations integrated

Based upon the findings from section 1, and the interviews with practitioners from section 2, we initially integrated the following features into the Rhizoma VR experience:

Rather than starting the experience without any context, users are first shown an accessibility menu screen which allows them to tweak a number of settings to their preference. To cycle through each of the menu options, users had to nod like they indicating “yes”, or agreement. To move the sliders for each of the menu options, they had to gesture with a single head shake, like they were indicating “no”, or disagreement. No instructions were provided for the gestures required, allowing an exploration of how intuitive navigation was within the experience.

The accessibility menu screen contained the following settings (Figure 3) which were all read aloud with voice over:

- Volume, complete with a slider bar. It was important the volume was the first option on the screen, the rationale being that if a user could not see the text, they would be able to hear what was displayed.
- Voice: Five different voices were built-in for use during voice over, with a choice between male, female, and non-binary voices. All options were natural sounding, AI-generated voices created with Eleven Labs (2025)
- Text size – controlled with a slider bar.
- Brightness – controlled with a slider bar.
- Contrast – controlled with a slider bar. A colour palette is displayed underneath to show the changes made by slider movements.
- High contrast mode – a variety of preset contrast modes which participants can cycle through (black text on a white background, black text on a yellow background, black text on a red background, yellow text on a black background, red text on a black background – demonstrated in Figures 4 and Figure 5).

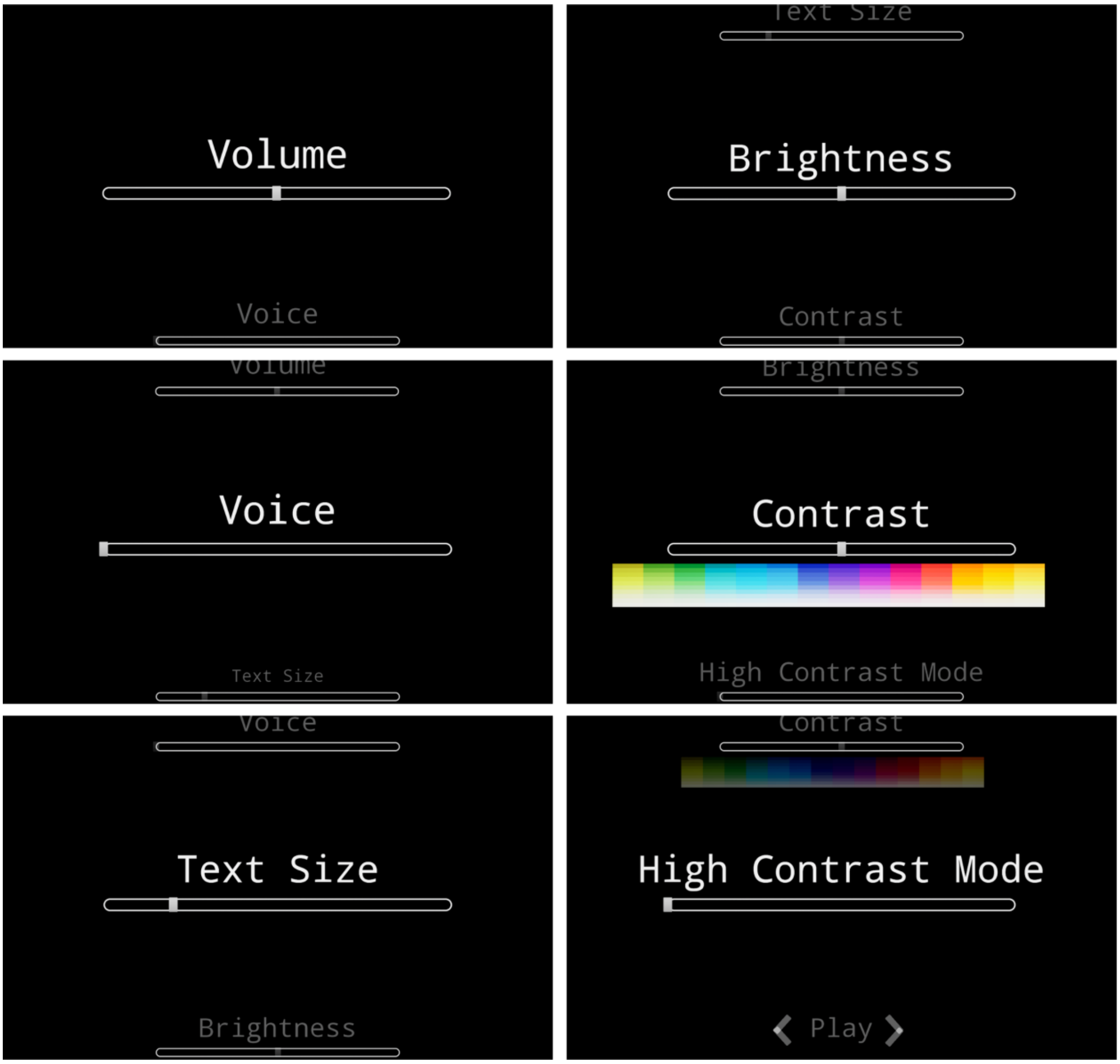

Figure 3 – From top to bottom, column one shows the volume, voice, and text size sliders. Column two shows the brightness, contrast, and high contrast mode sliders.

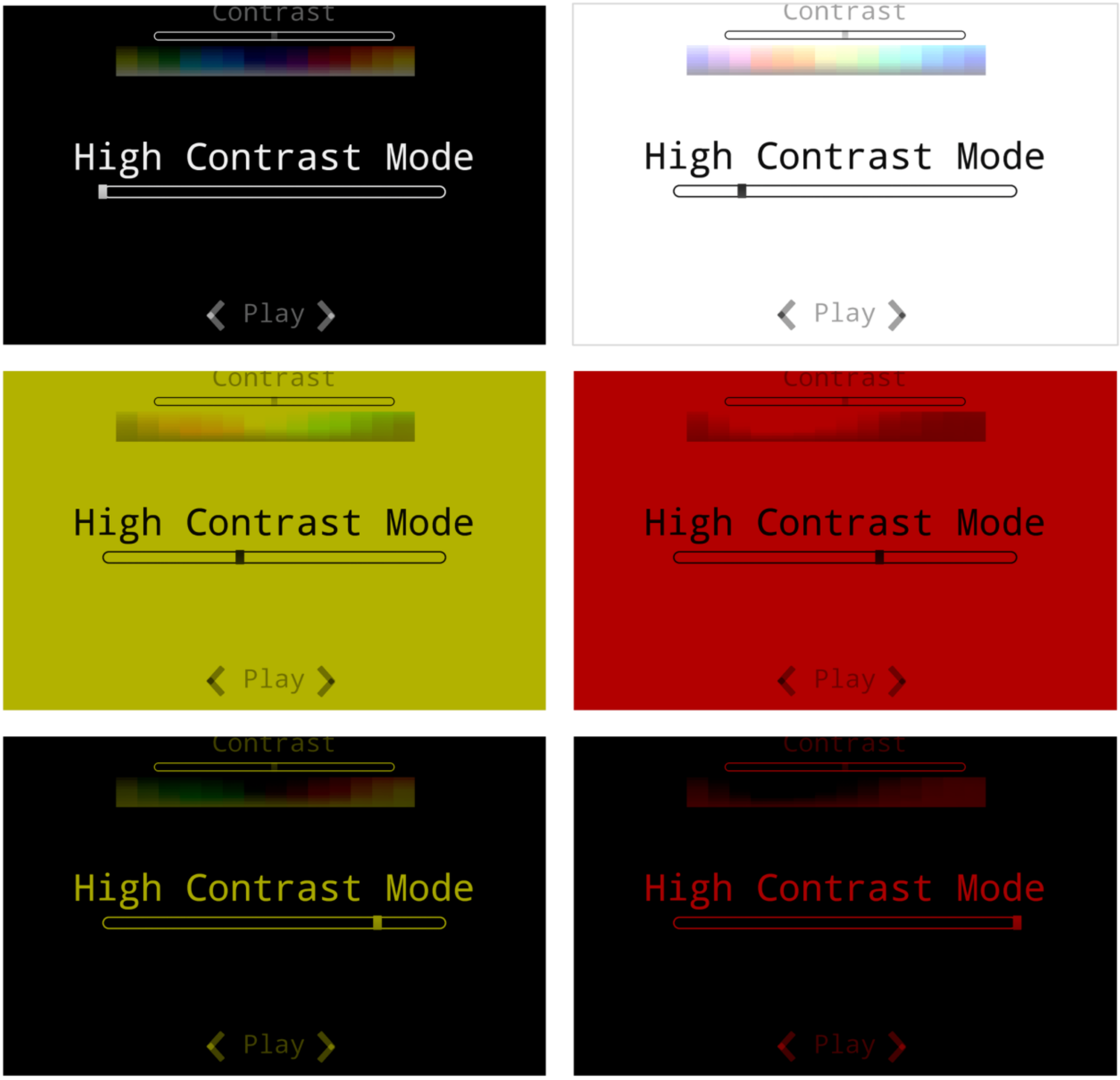

Figure 4 – Variety of contrast modes available in the Rhizoma VR experience.

Each of the three environments within Rhizoma VR were also given a voice over once the user reached the appropriate location. The voice over text for each of the areas was as follows:

- Desert – “You are standing in the middle of a windy desert surrounded by small, rippling sand dunes. The sun pokes through the slightly misty sky.”
- Kelp forest – “A kelp forest now appears before you. Giant pieces of kelp rise out of the sand, towering over you. The sunlight fades, casting shadows that dance around you. The area grows darker, as the forest embraces you in its eerie, otherworldly stillness.”

- Fireflies – “You step into the darkness, surrounded by hundreds of glowing fireflies flickering in every direction. Their soft lights stretch endlessly, or so it seems...”.

Figure 5 – From top to bottom, column one shows the desert, kelp forest, and fireflies in “standard” mode, i.e., without any augmentations. Column two shows the same view in high contrast mode where the colours are inverted.

RNIB Scotland hosted their Inclusive Design for Sustainability (IDS) conference at the Glasgow Science Centre on March 17th and 18th 2025. The Rhizoma VR experience was exhibited in the IDS Tech Marketplace throughout the conference, serving as an informal pilot study, with approximately 20 delegates of varying ages and levels of sight loss exploring the experience. Based upon feedback from delegates, and Dr Shepherd's observations at the conference, additional augmentations were integrated into Rhizoma VR to improve accessibility and the user experience.

Without guidance, delegates struggled to interpret the head-based gestures required to navigate through the accessibility menu and VR experience. Additionally, the firefly portion of Rhizoma was initially designed as an open-ended experience, however it was felt that an audio cue was needed to signal to participants they had reached the end and there was nothing more to explore.

Cognisant of the issues identified with the informal pilot study, the following augmentations were also implemented into Rhizoma VR:

Several new screens were shown at the start of the experience to guide the user, i.e., when the user first wears the headset, and before they are taken to the accessibility menu. These screens served as a tutorial, helping users understand the head gestures required to proceed through the experience. The user remains on each screen until they perform the appropriate gesture required. Each screen featured white text on a black background, and all text was read aloud with a voice over. New screens include:

- Screen one, Figure 6 (the “yes” gesture screen) states: “To select different menu options, nod your head firmly once downward or upwards (like you are saying ‘yes’.)”.

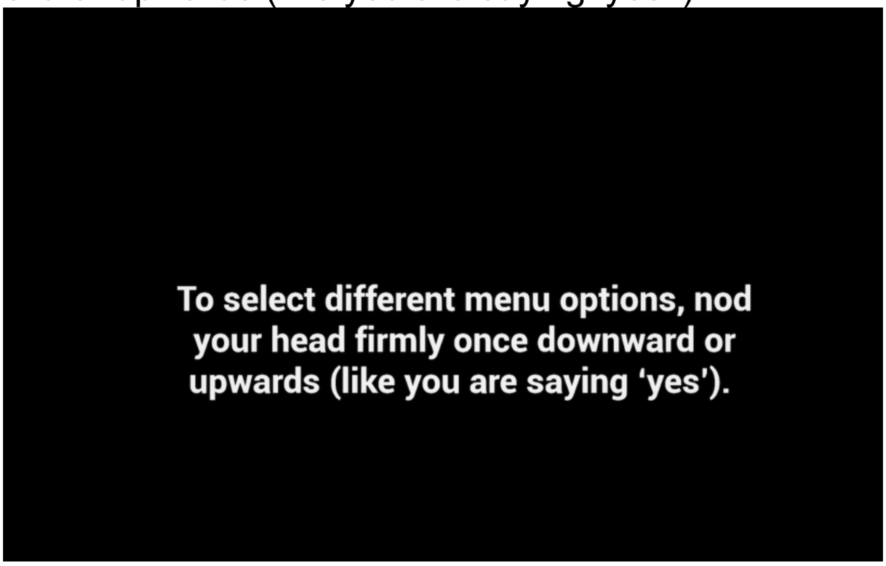

Figure 6 - the “yes” gesture screen.

- Screen two, Figure 7 (the “no” gesture screen) states: “To modify these menu options, move your head left or right for each increment (like you are saying ‘no’).”.

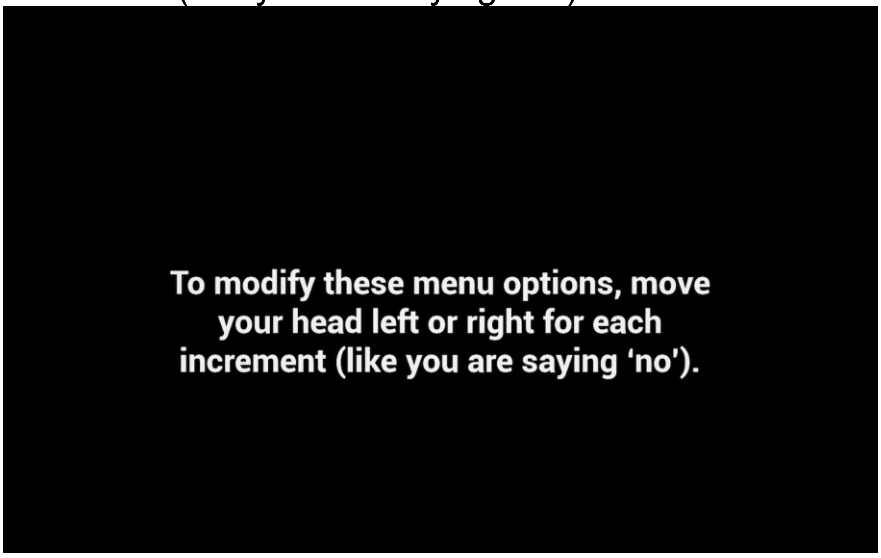

Figure 7 - the “no” gesture screen.

- Screen three, Figure 8 states (the “continue” gesture screen): “<Continue>”, asking the user to “use right or left head movements to continue”. Users are then shown the accessibility menu.

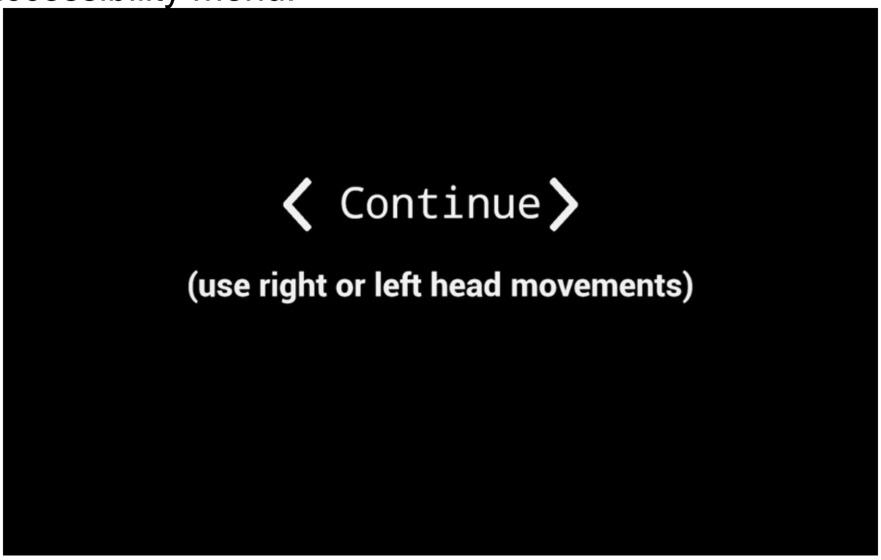

Figure 8 - the “continue” gesture screen.

- On performing the requisite head gesture to indicate they are ready to play the game, the user is shown a screen which states “Tilt your head downwards to move forwards through the experience – you are free to explore.” (Figure 9). This is shown for a few seconds, then the user is immersed in the Rhizoma VR experience.

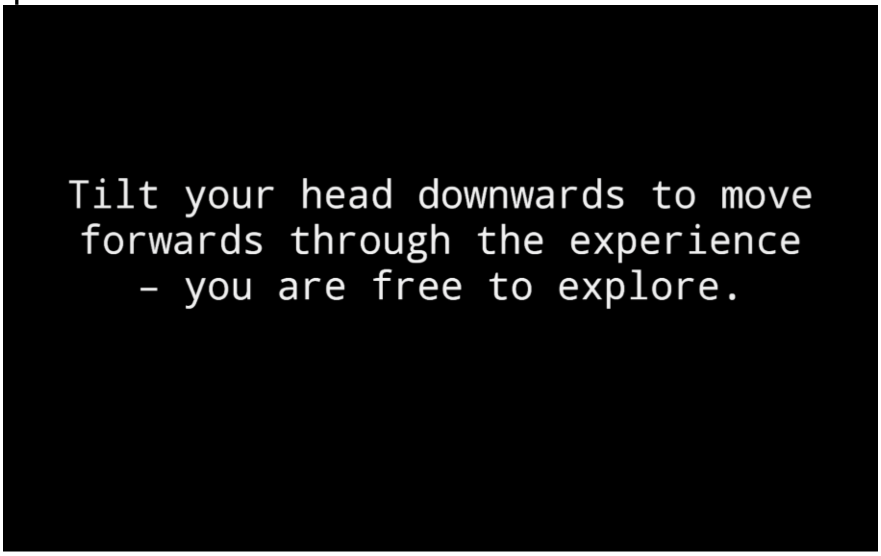

Figure 9 – explaining to the user how to move forward.

Additional features added to support navigation within Rhizoma VR:

- The level of head tilt required for the user to move forward was reduced to create a more comfortable experience, and to help users explore the environment.
- A limit on the distance you can travel through the fireflies as delegates often became stuck in this space. A voice over was added to indicate the experience had ended and the screen faded to black.

A summary of the augmentations implemented and the rationale for these changes can be found in Table 2.

Augmentation	**Implementation and rationale**
Volume	Volume slider. Inspired by findings from: Tzovaras et al., 2004; May et al., 2020.
Brightness	Brightness slider. Inspired by findings from: Zhao et al., 2019;
Clear instructions	Rhizoma VR contains a number of instructional screens. Inspired by findings from: Wedoff et al., 2019
Contrast	Contrast slider – slightly tweaks the standard contrast. Inspired by findings from: Zhao et al., 2019; Zhao et al., 2015;

Head gestures	Users can navigate using head movements; no additional controllers are required. Inspired by findings from: Gonzalex Penuela et al., 2022;
High contrast	Distinct contrast options users can cycle through with a slider. Inspired by findings from: Zhao et al., 2019; Zhao et. al 2015;
Text size	Text size slider. Inspired by findings from: Zhao et al., 2019;
Voice choices	Several realistic sounding AI-generated voices – option selected with a slider. Inspired by findings from: Thevin et al., 2020; May et al., 2020.
Voice over	Menu items, instructions, and zones within the Rhizoma VR experience are read aloud. Inspired by findings from: Zhao et al., 2019; Maidenbaum et al., 2013; Maidenbaum et al., 2016.

Table 2 – overview of augmentations placed in the Rhizoma VR experience, underpinned with research.

An overview of the additional augmentations can be found in the flow diagram in Figure 10. Following the inclusion of these additional augmentations, the Rhizoma VR experience was ready for more formal user testing.

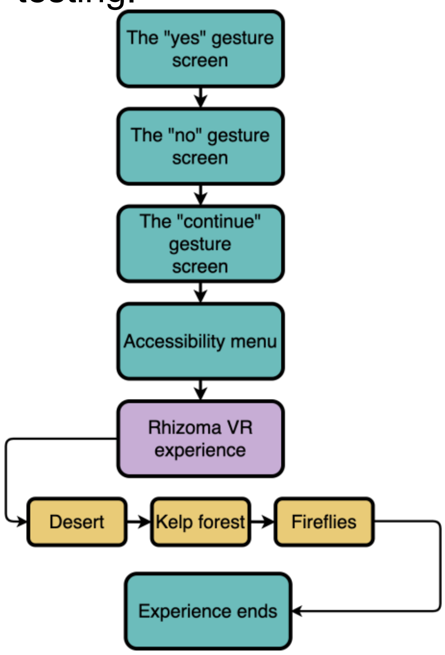

Figure 10 – flow diagram showing the different screens within the prototype.

4 User evaluation

To evaluate the efficacy of the accessibility augmentations we made to the Rhizoma VR experience, we conducted a user evaluation with participants with varying levels of sight loss. The section discusses our methodology and findings.

4.1 Ethical considerations

The development and evaluation of XR toolkit and associated Rhizoma VR experience was approved by Abertay University's Ethics Committee (submission no. EMS9425).

4.2 Pilot study

As previously mentioned in section 3.4 Augmentations Integrated, the Rhizoma VR experience was showcased at RNIB Scotland's Inclusive Design for Sustainability (IDS) conference at the Glasgow Science Centre on March 17th and 18th 2025. Approximately 20 delegates tried out the experience at Abertay University's stand at the IDS Tech Marketplace. Comments from delegates informed the additional enhancements included in the experience.

Additional informal feedback was also gained from delegates. For example, one of the blind and partially sighted delegates discussed their previous experience with VR headsets when trying to play games at home. They noted they had trouble with text, as quite often it was set at a fixed distance, and thus, difficult to read. To overcome this, the delegate had to remove their headset, view the text on his monitor which made use of accessibility tools, then put the headset on again – a cumbersome process. In the case of Rhizoma VR, the delegate was able to read menu text and praised the ability to modify text size.

Positive comments were also received regarding the flexibility of the menu options, and the natural-sounding tones of the AI voices chosen for voiceover.

A common sentiment among delegates with sight loss was their uncertainty about how they could engage with XR experiences. Many had not had the opportunity to try a VR headset before, and several noted being reluctant to buy one for home use given the cost and lack of information of what games would be accessible for them.

Overall, delegates were eager to follow the toolkit work's progress in the hope of future accessible XR experiences.

4.3 Augmented Rhizoma VR prototype evaluation

The user evaluation questionnaire was created in Microsoft Forms, owing to the need for GDPR compliance.

All participants indicated they wanted the contents of the Microsoft Form read out to them by the researchers. Prior to playing through the Rhizoma VR experience, participants were asked to provide informed consent, before being asked some basic demographic questions, including age, gender, level of vision impairment, and assistive technologies used.

Following this, there were then some questions about gaming experience focusing on frequency of play, and accessibility challenges, before exploring VR experience (propensity to VR and motion sickness, usage of VR devices, VR device frequency of use, last time VR was used, comfort with types of VR experiences and time spent in these experiences).

Participants were then asked to wear a VR headset (assistance was provided from the researchers) and complete some tasks within a VR menu "the first task: can you adjust the text size of the menu?, The second task: Can you change the voice in the menu?, You can change other features to suit before entering and playing through the Rhizoma VR experience.", before entering the Rhizoma VR experience.

Tasks one and two were designed to assess cognitive load as previous studies had indicated issues with overload (Zhao, 2024; May et al., 2020). Once they had completed the experience (or decided they no longer wanted to continue in VR), they then proceeded with the remainder of the questionnaire.

In the second half of the questionnaire, participants completed simplistic version of the NASA-TLX (NASA task load index) questionnaire[3] (NASA Ames Research Center, 1988; Hart and Staveland, 1988) for each of the tasks and were asked to rate overall usability with the SUS (system usability scale), before addressing some open-ended, free-text questions about their experience. To conclude the Rhizoma VR study, participants were given a debrief, including further information about the study, and were rewarded with a £10 Amazon voucher for participation.

4.4 Results

A total of 10 participants with varying levels of sight loss took part in the user evaluation (n=10). The number of participants is consistent with studies outlined in Section 1 which conducted studies with blind and partially sighted people. Each participant took approximately 30-40 minutes to complete the questionnaire and a playthrough of Rhizoma VR.

User testing took place across two sessions in April 2025. The first took place at RNIB Scotland's headquarters in Edinburgh, and the second took place at Visibility Scotland's monthly meet-up for younger people at their office in Glasgow.

4.4.1 Demographic information

4.4.1.1 Age and gender

While participant ages varied, the majority were young adults aged 18-24 (n=4). The remaining participants were distributed across older age groups: 35-44 (n=2), 45-54 (n=1), 55-64 (n=1), and 65+ (n=2). When asked "Which gender do you identify with?", the results highlighted an even split between male and female (n=5 for each category).

4.4.1.2 Level of vision impairment and use of assistive technologies

A broad range of levels of vision impairment were represented in our user evaluation, ranging from mild vision impairment to blindness (full results are shown in Table 3). The majority of participants in our study (n=5) described their level of vision impairment as severe.

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[3] This measures subjective workload i.e., how mentally and physically demanding a task feels to the person performing said task.

Level of vision impairment	Number of responses
Mild vision impairment (some difficulty seeing but manageable without assistive devices)	1
Moderate vision impairment (difficulty seeing even with corrective lenses, may use assistive devices)	3
Severe vision impairment (very limited vision, rely on assistive devices or braille)	5
Blind (no functional vision)	1

Table 3 – responses to the question “How best would you describe your level of vision impairment?”.

Participants made use of a wide range of assistive devices as indicated in Table 4. One participant indicated headphones were an assistive technology enabling them to effectively hear voiceover. Many were familiar with mobile accessibility applications (n=8) and made use of screen readers (n=6), hinting that participants may quickly feel acquainted with the augmentations integrated into Rhizoma VR.

Assistive technologies used	Count
Screen Readers (e.g., JAWS, NVDA, VoiceOver, TalkBack)	6
Screen Magnifiers (e.g., ZoomText, SuperNova, built-in magnifiers)	5
Refreshable Braille Display (e.g., HumanWare Brailliant, Focus Braille Display)	0
Braille Notetaker (e.g., BrailleNote Touch, BrailleSense)	1
Voice-Controlled Assistants (e.g., Siri, Alexa, Google Assistant)	7
Dictation Software (e.g., Dragon NaturallySpeaking, built-in speech-to-text)	5
Mobile Accessibility Apps (e.g., Seeing AI, Be My Eyes, Lookout, Aira)	8
Wearable Assistive Devices (e.g., OrCam MyEye, Envision Glasses, Dot Watch)	2
Large-Print or High-Contrast Keyboards	4
Talking Watches, Clocks, or Calculators	3

Table 4 – responses to the question “Which assistive technologies do you typically use (select all that apply)?”.

4.4.2 Challenges faced when gaming

When asked “How frequently do you play video games/spend time gaming?”, of the 9 respondents who indicated they played or had previously played video games (n=2 played daily more than 2 hours, n=3 played daily between 1-2 hours, n=1 played weekly, n=1 played monthly, n=1 played a few times a year, n=1 played in the past but had since given up), all indicated they had faced accessibility challenges. When asked to describe accessibility challenges in games, a number of themes were derived from the free-text responses, which are explored in the subsections below.

4.4.2.1 Screen reader compatibility

Several participants noted that they had experienced issues with screen readers and related software. Operating system screen readers were not compatible with all games, and it was indicated there were also challenges with using screen readers on games consoles.

Although some games were praised for having screen readers built-in, sometimes no instructions were provided to indicate the native screen reader should be switched off to avoid conflict. Poor instructions were cited as causing further accessibility issues - depending on the set-up of the game, these may be in an unreadable format.

The sound-mixing of in-game effects were also cited as an issue - an example was given where an in-game monster may make a sound and conflict with the text or description the screen reader is interpreting.

4.4.2.2 Limited accessibility settings

Lack of accessibility features in some games, or accessibility options which did not perform efficiently meant those experiencing sight loss were unable to play them. One participant noted particular challenges with their MacOS machine in comparison to their Windows device and felt the security settings on MacOS restricted the use of accessibility tools.

4.4.2.3 In-game graphics

Poor colour contrast within games was cited as a challenge for those with sight loss, making it particularly difficult to track objects in-game. Although it was noted graphics had improved considerably in more modern games, realistic environments deemed "dark" or "murky" made navigation difficult due to a lack of contrast.

Lack of in-game highlighting was also cited as an issue, meaning players may be unable to tell if an item is interactive or they may be unable to discern enemies to attack due to the lack of hit indicators.

4.4.2.4 Small text size

It was noted that some older games do not feature a scalable user interface. This means that when using a high-resolution display, the resolution cannot be adjusted, leading to small text which is hard to read. One participant highlighted this caused additional discomfort when playing as they needed to lean forward to view the text leading to neck pain (termed “gamer neck”). One participant noted challenges due to the differing focal length in each of their eyes, often leading to double vision.

4.4.3 Previous experience with VR technologies

A series of questions were asked to ascertain participants previous experience with VR, and frequency of use. Just over half of the participants said they had used VR previously (n=6), indicating that there is an appetite for such experiences amongst the blind and partially sighted community, and that static experiences (standing or seated) are preferred. Table 5 features the full breakdown of results.

Questions	Answers	Count
Do you experience motion sickness?	Yes	2
	No	5
	Maybe	2
Have you used virtual reality (VR) devices before?	Yes	6
	No	4
How frequently do you use VR?	Once a week	2
	2-3 times a year	3
	Prefer not to say	1

When was the last time you used VR?	Last 7 days	2
	Last year	1
	Over 1 year ago	3
Which types of VR experiences are you comfortable with?	Seated	6
	Roomscale	4
	Static standing	5
	Moving using teleportation	1
	Moving using a thumbstick	4
How long can you comfortably spend in VR?	10-30 minutes	2
	31-60 minutes	1
	1-2 hours	1
	Prefer not to say	2
Do you experience VR sickness?	Yes	1
	No	5

Table 5 – participant experience with VR.

4.4.4 Rhizoma usability evaluation

Only nine of the participants were able to proceed with the full Rhizoma VR usability evaluation; restrictions with the hardware within the Meta Quest Pro headset meant it failed to detect one participant was present as their high-prescription glasses caused a reflection. This suggests that hardware manufacturers should evaluate their devices with a diverse population to ensure they can be adapted for a wide range of needs.

4.4.4.1 Task one – menu text size

Participants were asked to rate their experience across six dimensions of the NASA-TLX questionnaire when changing the size of the menu text. This measures subjective workload i.e., how mentally and physically demanding a task feels to the person performing it. A simplified version was used, containing a 7-point Likert scale for each dimension (1 – very low, 7 – very high). The performance dimension is reversed coded (i.e., the score is subtracted from 8 for analysis).

The mean workload rating per participant ranged from 1.33 to 2.83, with one outlier with a value of 4. The mean workload rating across all participants was 1.98 which can be rounded up to 2. This is indicative that a low-level of effort was required to change the menu text. An average rating for each of the dimensions can be found in Table 6. Overall, this task was found to generate a low cognitive load.

Dimensions	Average Score	Rating
Mental Demand	2	Low mental demand
Physical Demand	2.222222222	Low physical demand
Temporal Demand	1.888888889	Low temporal demand
Performance	1.111111111	Very low performance demand
Effort	2.444444444	Low effort
Frustration	2.222222222	Low frustration

Table 6 – average scores from the NASA-TLX dimensions.

Participants were then asked, “Do you have any comments about this task?” to gain some qualitative feedback. A mix of comments were received. One participant cited the weight of the headset as being problematic, feeling it was quite heavy, and may be uncomfortable if worn for extended periods of time. Others cited the menu options as perhaps being a little unclear at this stage, finding it difficult to discern the difference in text size displayed when they changed it. Others found themselves also adjusting the high contrast option, noting it was rather bright.

4.4.4.2 Task two – menu voice change

Participants were asked to rate their experience when changing the voice used in the menu and Rhizoma VR experience. Again, the simplified NASA-TLX questionnaire was used.

The mean workload rating per participant ranged from 1 to 2.66, with one outlier with a value of 3.66. The mean workload rating across all participants was 1.74 which can be rounded up to 2. This is indicative that a low-level of effort was required to change the voice in the menu. An average rating for each of the dimensions can be found in Table 7. Overall, this task was found to generate a low cognitive load.

Dimensions	Average Score	Rating
Mental Demand	1.444444444	Very low mental demand
Physical Demand	1.888888889	Low physical demand
Temporal Demand	2.333333333	Low temporal demand

Performance	1.444444444	Very low performance demand
Effort	1.888888889	Low effort
Frustration	1.444444444	Very low frustration

Table 7 – average scores from the NASA-TLX dimensions.

Participants were again asked “Do you have any comments about this task?”. Positive comments were received about the choice of voices at this stage. One participant noted the voices were nice to listen to, finding them human rather than robotic, and enquired which package was used. They highlighted that other games would benefit from this. Within the accessibility menu, participants appreciated the opportunity to preview the voices and found the range interesting.

4.4.4.3 SUS score

SUS scores varied between 60 and 95 (mean = 78.3, SD = 11.59, n=9), which suggests the usability of the VR experience was generally considered to be above average (68), although two scores fell below this threshold (60 and 65). To assess the internal consistency of the survey, Cronbach’s alpha was calculated, α= 0.740, indicating an acceptable level of consistency within participant answers.

4.4.4.4 Qualitative responses

To conclude the questionnaire, participants were invited to give free text responses to a series of questions on their experience.

4.4.4.4.1 Menu interactions

Participants indicated that although the accessibility menu was basic, it worked well. The white text on the black background was well received and deemed to be gentle on the eyes. Conversely, the first high contrast option (black text on a white background) was deemed to be overpowering by two participants and may not be suitable for those with photosensitivity.

Regarding navigation within the menu, one participant noted the use of head-based gesture created a bit of a learning curve, but others found it easy once they became used to the motions. There was some discussion around describing the gestures; a participant who described themselves as blind indicated that although these gestures might seem natural to a sighted person, it was potentially difficult for someone with sight loss to envisage the impact of these movements, likening it to challenges experienced when navigating through rows and columns in a spreadsheet. One participant indicated they were not used to navigating in this way because they rely on screen readers.

Potential improvements were noted, for example, when the bottom of the accessibility menu is reached, it should loop back to the beginning to reduce the number of head movements required. The option for changing the text size could have had exemplar text showing the full range of sizes available.

4.4.4.4.2 Menu voice options

Comments regarding the voiceover options in the menu were generally positive.

Voices were deemed to be clear, pleasant to listen to, and had a variety of different pitches. They also thought there could have been more use of these voices in the experience delivering instructions. The voice named "River" was found to be a little quiet, and this may relate to the voice pitch.

Participants were keen to have more voice options integrated into the menu, with a range of accents, which were easy to understand.

4.4.4.4.3 Menu contrast and colour options

Participants commented positively on the high contrast colour options, though as mentioned previously, the option featuring black text on a white background was viewed as "too bright".

Many of the participants did not see any benefit from the contrast slider option; the increments are subtle, and it was not clear how it affected the VR experience. It was suggested a thumbnail image from the VR experience could be included as part of the menu to help communicate the slider changes in a more effective manner.

4.4.4.4.4 Accessibility options

Comments on accessibility options were limited. Positive comments included the variety of options, with one participant saying this should be used as an exemplar to show to game companies on how to develop an effective menu system. It was also noted that the typeface used was deemed clear and easy to read.

Additional suggestions to improve the menu included audible tooltips, and supporting information for each menu option, such as lingering over an option for a few seconds, and the voiceover will describe what the menu option does.

4.4.4.4.5 Rhizoma VR navigation

The navigation through the different zones proved to be a negative point raised by participants. Asking participants to tilt their head downwards to move forward meant they could not see the horizon in what a rather featureless environment is; this made it easy for participants to lose their sense of direction. This was a sentiment echoed by a call for additional narration within the game to serve as navigational cues, and to help fully describe the experience.

Several participants did not know how to navigate the kelp forest when they first encountered it. To them, it was not clear if they needed to find a gap to move in to, and because it was so dark inside the forest, it was not clear if they were moving forwards. Once the fireflies were reached, a sense of equilibrium was regained.

It was suggested that alternate controllers could be provided in the event participants have physical limitations and issues with head and neck movements.

4.4.4.4.6 Additional comments about the Rhizoma VR experience

Participants generally indicated they enjoyed the Rhizoma VR experience.

One participant noted what while they usually experienced double-vision due to different focal lengths in each eye, they had no problem with this in the VR environment, and their vision felt sharper. It is hypothesised that this is due to the close proximity of the VR headset to the eyes.

The audio and different tones were also well received, creating an atmospheric environment.

4.4.4.4.7 Suggested enhancements for people with vision impairments

A number of suggestions were received to help make VR experiences accessible for blind and partially sighted people.

These included catering for a variety of different sight conditions (and supporting those who may be deaf or hard of hearing) and adding extra confirmation screens when selecting menu options, so options are not mistakenly chosen.

There was also a call to augment sound design through the use of footsteps sound effects or audio indicators to convey movement, along with having audible objects in the environment or instructions to move towards a sound contextual to the environment (diegesis).

On the whole, participants were pleased there was an ongoing, concerted effort to make games more accessible, highlighting that 20 years ago, there was nothing really in this space, with only access to very basic games.

4.5 Conclusions and recommendations

Findings from the user evaluation established that the Rhizoma VR experience was both enjoyable and usable for participants with differing degrees of sight loss, from those who described themselves as having a mild vision impairment to those who were blind. In particular, the sound design received positive comments.

The accessibility menu was also well received; the experience addressed some of the challenges participants described in relation to their prior experience with gaming, such as screen reader or voice over functionality and range of accessibility settings (noting the importance of being able to change text size). Navigating through these menu options through the use of head gestures was shown to have induced a low cognitive load, meaning it was relatively straightforward.

Some portions of the Rhizoma VR experience received negative comments, and these can help inform future work around accessible design of XR experiences. Participants indicated that there should be an alternative to head-based gesture navigation which would make the experience inclusive for people who may have physical limitations. Additionally, they felt it would be useful to have a waypoint or horizon to navigate through the open space in the VR world; currently moving forward in Rhizoma VR requires tilting the head downwards slightly, which can obscure the horizon for some individuals. Lastly, it was highlighted that one of the high contrast modes should come with a warning as it may not be suitable for people with photosensitivity.

Several future recommendations were gathered as part of Rhizoma VR user evaluation, which again has the potential to inform future work. Additional features suggested by participants included the option to adjust the focal length of menu text, additional supporting information on the menu, such as a guide to possible text sizes available, and the incorporation of footsteps to indicate movement.

To conclude, there was a clear enthusiasm among participants to leverage XR, reflecting their overall satisfaction with the efforts to enhance game accessibility and inclusivity for BPS.

5 Concluding remarks

Overall findings from this report highlights the importance of testing early and often with BPS during the development of XR experiences. Furthermore, such experiences should incorporate flexibility where possible, allowing individuals to customise the experience to suit their needs. Feedback provided to the user should be carefully considered, balancing a multimodal approach (i.e., avoiding reliance on visual cues, whilst incorporating, audio cues and haptics) and balancing concerns around cognitive overload.

Interviews with XR practitioners revealed that whilst they already make use of existing guidelines around accessibility, they try to engage with BPS, i.e., those with lived experience in the first instance. That said, practitioners still face many hurdles when developing XR experiences; these range from hardware and tooling limitations, constraints around resourcing, budgets, and testing schedules, and catering to a wide range of intersectional needs. Emerging technologies may offer a solution here, with usage of eye tracking, haptics, and AI becoming ubiquitous.

We augmented an existing VR experience, Rhizoma VR, which draws on best accessibility practices derived from our literature review and practitioner interviews. The user evaluation showed XR experiences can be accessible for BPS when there is an appropriate level of customisation embedded through the use of an accessibility menu. It also highlighted that there was a clear appetite amongst BPS for the creation of more accessible XR games and experiences.

Moving forward, it is essential that all stakeholders, BPS with lived experience, developers, platforms, specialist charities, policymakers, and academics, collaborate to champion inclusive XR experiences and games. This toolkit offers a rich source of information to support the games industry in achieving this goal.

Glossary

- 360-degree video: video which is shot in all directions from one position, creating an immersive experience, placing the user inside a panoramic sphere which they can explore.
- Ambisonic audio: a sound format which is composited from multiple audio channels, allowing playback on speaker configurations from mono audio to full spatial audio.
- Binaural audio: spatial audio that has been encoded to give the impression of 3D sound when delivered through headphones.
- Blind driving assists: audio cues within a driving or racing game which provides feedback to the player regarding information such as speed, position on the track, and track navigation.
- Deep learning: falls into the overarching domain of machine learning and uses multi-layered neural networks (a series of connected nodes) to perform tasks.
- Echolocation: a system where sound waves are reflected off objects to help determine their location. This can be simulated in extended reality environments.
- Force feedback: feedback which simulates physical sensations.
- Foveated rendering: a technique which makes use of eye tracking to improve image quality in central vision and reduces the quality in peripheral vision. In the context of XR, this means the area the user is looking at will be rendered in high-quality, and the rest of the area in lower quality (also supports efficient rendering of a scene).
- Gaze tracking: this makes use of eye tracking to determine where the user is looking.
- Generative AI: the use of generative models to create output, for example images, text, and videos.
- Haptics: devices or peripherals which simulate the feeling of real-world touch or sensations.
- Head gestures: head movements made whilst wearing an XR headset which controls facets of the immersive experience.
- High contrast mode: a setting which allows colour contrast to be modified to improve viewability.
- Peripheral remapping: where peripherals such as game controllers have options allowing the user to reconfigure the actions performed by each button press.

- Screen reader: assistive technology which interprets software interfaces into spoken audio enabling them to be perceived and operated by BPS.
- Sensory substitution device: a system that converts information from one sensory modality into another to compensate for sensory impairments.
- Spatial audio: a 3D audio effect creating virtual surround sound.
- Spatial cognition belts: a device which provides haptic feedback concerning a players' environment in terms of objects and spatial awareness.
- Tactile displays: a device which translates information shown on the screen into haptic feedback, through the likes of vibrations, or patterns created with dots. It can also be used to produce braille.
- Talkback: a screen reader built into Android platforms.
- Vibrotactile feedback: tactile feedback delivered through vibrations.
- Voice command vs. voice control: voice commands are specific instructions or phrases used to perform a specific task on a system. Voice control is broader than this, allowing a person to more fully interact with a system using voice (i.e., control over the whole system).
- Voiceover: a screen reader built into iOS platforms.
- Wizard of Oz prototyping: a user-research method where users are asked to interact with a system which they believe is computer controlled, but in fact is partially controlled by a human.

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Appendices

Appendix A Rhizoma VR contrast modes

Desert

The desert zone of Rhizoma, represented in each of the different contrast modes (Figure 11). In column one, top to bottom, the modes are as follows: black text on a white background (standard experience), black text on a yellow background. In column two, top to bottom: the following modes are represented: black text on a red background, yellow text on a black background, red text on a black background.

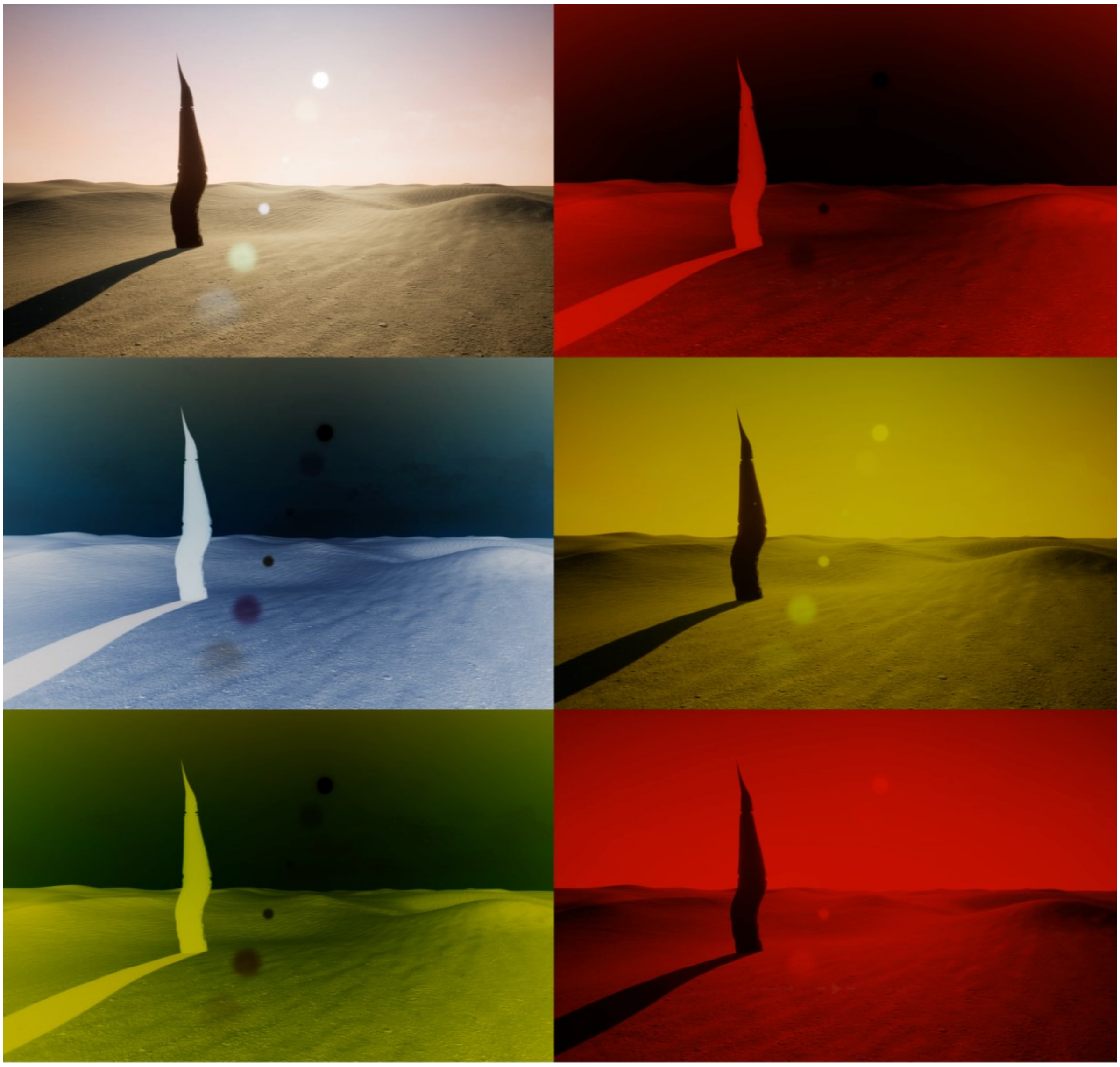

Figure 11 – The effect of different contrast modes on the desert zone.

Kelp forest

The kelp forest zone of Rhizoma, represented in each of the different contrast modes (Figure 12). In column one, top to bottom, the modes are as follows: black text on a white background (standard experience), black text on a yellow background. In column two, top to bottom: the following modes are represented: black text on a red background, yellow text on a black background, red text on a black background.

Figure 12 – The effect of different contrast modes on the kelp forest zone.

Fireflies

The firefly zone of Rhizoma, represented in each of the different contrast modes (Figure 13). In column one, top to bottom, the modes are as follows: black text on a white background (standard experience), black text on a yellow background. In column two, top to bottom: the following modes are represented: black text on a red background, yellow text on a black background, red text on a black background.

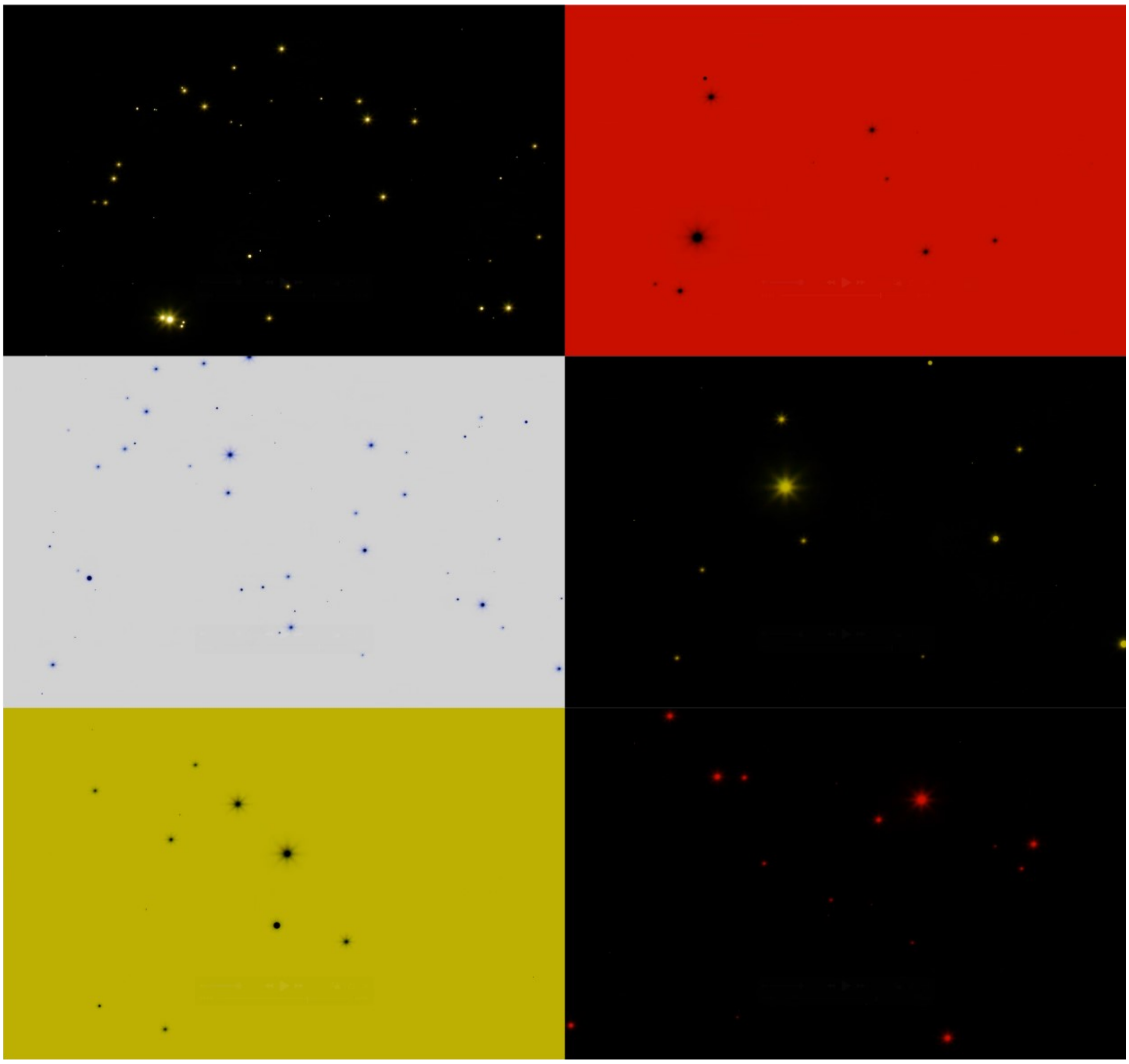

Figure 13 – The effect of different contrast modes on the firefly zone.

Appendix B – User evaluation questions

Below are the questions which were asked as part of the evaluation.

Demographic Information
Which age bracket are you in?

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65+
- Prefer not to say

Which gender do you identify with?

- Male
- Female
- Non-binary
- Prefer not to say
- Other <text box to enter the relevant option>

How best would you describe your level of visual impairment?

- No visual impairment (I can see clearly)
- Mild visual impairment (some difficulty seeing but manageable without assistive devices)
- Moderate visual impairment (difficulty seeing even with corrective lenses, may use assistive devices)
- Severe visual impairment (very limited vision, rely on assistive devices or braille)
- Blind (no functional vision)
- Prefer not to say

Which assistive technologies do you typically use (select all that apply)?

- Screen Readers (e.g., JAWS, NVDA, VoiceOver, TalkBack)
- Screen Magnifiers (e.g., ZoomText, SuperNova, built-in magnifiers)
- Refreshable Braille Display (e.g., HumanWare Brailliant, Focus Braille Display)
- Braille Notetaker (e.g., BrailleNote Touch, BrailleSense)

- Voice-Controlled Assistants (e.g., Siri, Alexa, Google Assistant)
- Dictation Software (e.g., Dragon NaturallySpeaking, built-in speech-to-text)
- Mobile Accessibility Apps (e.g., Seeing AI, Be My Eyes, Lookout, Aira)
- Wearable Assistive Devices (e.g., OrCam MyEye, Envision Glasses, Dot Watch)
- Large-Print or High-Contrast Keyboards
- Talking Watches, Clocks, or Calculators
- I do not use assistive technologies
- Prefer not to say
- Other <text box to enter the relevant options>

Gaming experience

How frequently do you play video games/spend time gaming?
- I play daily (more than 2 hours)
- I play daily (1- 2 hours)
- I play weekly
- I play monthly
- I play a few times a year
- I played video games in the past, but I've since given up
- I don't play video games
- Prefer not to say

Have you faced accessibility challenges when playing video games?
- Yes
- No
- Maybe
- Prefer not to say

Please describe the accessibility challenges you have faced when playing video games
<Open text response which only shows if the participant indicated "yes" or "maybe" above>

GLAM (galleries, libraries, archives, or museum) sector experience
Note: results related to this section are presented in our GLAM sector toolkit.

How frequently do you visit galleries, libraries, archives, or museums?
- I visit daily (more than 2 hours)
- I visit daily (1- 2 hours)
- I visit weekly
- I visit monthly
- I visit a few times a year
- I visited these spaces in the past, but I’ve since given up
- I don’t visit these spaces
- Prefer not to say

Have you faced accessibility challenges when visiting galleries, libraries, archives, or museums?
- Yes
- No
- Maybe
- Prefer not to say

Please describe the accessibility challenges you have faced when visiting galleries, libraries, archives, or museums
<Open text response which only shows if the participant indicated “yes” or “maybe” above>

VR experience questions
Do you experience motion sickness?
- Yes
- No
- Maybe
- Prefer not to say

Have you used virtual reality (VR) devices before?
- Yes
- No
- Maybe
- Prefer not to say

How frequently do you use VR?

- Every day
- Once a week
- 2-3 times a week
- 2-3 times a month
- 2-3 times a year
- Prefer not to say

When was the last time you used VR?

- Last 7 days
- Last month
- Last year
- Over 1 year ago
- Never
- Prefer not to say

Which types of VR experiences are you comfortable with (select all that apply)?

- Seated
- Static standing
- Roomscale
- Moving using teleportation
- Moving using a thumbstick
- Prefer not to say

How long can you comfortably spend in VR?

- 10-30 minutes
- 31-60 minutes
- 1-2 hours
- Over 2 hours
- Prefer not to say

Do you experience VR sickness?

- Yes
- No
- Maybe
- Prefer not to say

Usability testing

You will now be asked to complete some tasks within a VR menu, before entering a VR experience named Rhizoma. Leave this questionnaire open and return once you have completed the VR experience.

- The first task: Can you adjust the text size of the menu?
- The second task: Can you change the voice in the menu?
- You can change other features to suit before entering and playing through the Rhizoma VR experience.

Task one - menu text size
Please rate your experience when changing the size of the menu text.

Note – the questionnaire used was the standard NASA-TLX questionnaire (Hart and Staveland, 1988; NASA Ames Research Center, 1988).

The question "Do you have any comments about this task?" as a free text response was appended to the end of this section.

Task two - menu voice change
Please rate your experience when changing the voice used in the menu and Rhizoma VR experience.

Note – the questionnaire used was the standard NASA-TLX questionnaire (Hart and Staveland, 1988; NASA Ames Research Center, 1988).

The question "Do you have any comments about this task?" as a free text response was appended to the end of this section.

Overall experience
You will now be asked some questions about the overall experience with the menu system and Rhizoma VR experience.

Please read each of the statements and rate how you felt about the application as a whole (the menu system and the Rhizoma VR experience).

This section made use of the standard system usability scale (SUS) questionnaire (Brooke, 1996). This was followed by a number of other questions indicated below.

Did you experience VR sickness?

- Yes
- No
- Maybe
- Prefer not to say

Do you have any comments about the menu interactions (e.g., selecting different options)?
<text box to enter the relevant information>

Do you have any comments about the voice options in the menu?
<text box to enter the relevant information>

Do you have any comments about the contrast and colour options in the menu?
<text box to enter the relevant information>

Do you have any additional comments about the accessibility options in the menu?
<text box to enter the relevant information>

Do you have any comments about navigating the Rhizoma VR experience?
<text box to enter the relevant information>

Do you have any additional comments about the Rhizoma VR experience?
<text box to enter the relevant information>

Do you have any suggestions how to enhance the menu system and/or the Rhizoma VR experience for people with visual impairments?
<text box to enter the relevant information>