XR accessibility insights and toolkit: GLAM sector report

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Actionable insights

Key design principles for creating accessible XR experiences in the GLAM sector:

- Evaluate and co-design experiences with blind and partially sighted people.
- Establish dedicated resources (budgets) for inclusive design.
- Create rich audio content with differing levels of description.
- Incorporate natural-sounding (human or human-like) descriptions.
- Reflect on the use of seated or static standing XR experiences to overcome challenges with limited, dynamic space in GLAM sector buildings.
- Avoid relying on visual cues alone.
- Integrate touch-based feedback as an additional tactile response mechanism themed to exhibits.
- Support customisation of audio, text, contrast, and input mechanisms.
- Keep interfaces intuitive to avoid cognitive overload.

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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 GLAM (galleries, libraries, archives, and museums) environments often renders these experiences and exhibitions inaccessible for blind and partially sighted people (BPS). 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 GLAM sector to support development of accessible XR experiences and installations. Thus, we begin by presenting an overview of cutting-edge research at the intersection of accessibility and GLAM environments, with a particular focus on sight loss and VR experiences. We then present our findings derived from interviews with practitioners who curate and construct exhibitions in the GLAM space exploring challenges they may face when designing these experiences.

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 BPS. Rhizoma VR was then evaluated by a group of people with sight loss, to evaluate the efficacy of the augmentations integrated. Evaluation results helped corroborate our actionable insights targeting the GLAM sector, supporting the creation of accessible XR experiences.

XR experiences in a GLAM context can enhance existing exhibitions and spaces. Therefore, it is imperative that these XR experiences are accessible to a wide audience, especially for blind and partially sighted individuals. Developers and those in senior positions in the GLAM sector have a clear opportunity to support this through accessible design practices and installations; thus, we hope this report acts as a basis to towards facilitating the development of accessible XR experiences.

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Executive summary

Key recommendations from existing studies

- **Customisable accessibility settings:** for exhibits, incorporate a variety of built-in options to support diverse needs and multiple disabilities, for example, adjustable text size, and different contrast modes which are intuitive.
- **Navigation support:** GLAM spaces can be particularly challenging to navigate; these are dynamic spaces which can span multiple levels and may feature low light levels depending on which artefacts are on display. Focus should be placed on tools which assist with navigation.
- **Enriched audio content:** ensure audio content contains multiple levels of detail for aspects of a GLAM space, and allow users to skip portions entirely, or hear about certain artefacts in more detail.
- **Natural-sounding voice overs:** Avoid the use of robotic-sounding voices in descriptions of exhibits.
- **Tactile exploration:** include tactile elements in GLAM spaces however, these must be strongly linked and themed to the particular exhibition on display.
- **Anti-ocularcentric approach:** provide multi-modal feedback to visitors in GLAM spaces; do not rely on visual feedback alone, incorporate the likes of haptics and audio.

Key recommendations from the practitioner consultation

- **Embed Co-creation:** Prioritise and formalise the engagement of BPS throughout the entire lifecycle of XR experience development, from initial planning to prototyping, testing, and post-launch evaluation. Cultivate long-term, collaborative relationships with BPS communities and advocacy organisations.
- **Allocate Dedicated Resources:** Advocate for and secure dedicated budgets specifically for accessibility, covering consultation fees for BPS experts, staff training, and development of accessible features.
- **Champion Multi-Sensory Design:** Actively incorporate multi-sensory elements (e.g., spatial audio, descriptive audio, haptics, physical tactile aids) into XR projects to cater to diverse sensory needs and preferences.
- **Foster Continuous Learning:** Implement robust internal knowledge-sharing mechanisms and support ongoing professional development for staff in accessibility best practices, including

formal training for principle-sharing and involve blind and partially sighted people.
- **Plan for Dynamic Environments:** Develop strategies for ensuring VR experiences remain relevant and navigable within changing physical exhibition spaces, including clear communication about any discrepancies between virtual and physical layouts.

Key recommendations from the Rhizoma VR user study

- **Screen reader compatibility:** if an XR experience has a built-in screen reader, ensure it does not conflict with the system screen reader.
- **Accessibility settings:** ensure XR experiences 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 XR environments. Similarly, in XR specific 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, due to 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 XR experiences to support navigation.
- **Sound design:** to enhance the experience, audio indicators could be used to convey movement, along with audible objects in the environment. Provide a range of headphone types (e.g., bone

conducting headphones), to support immersion in potentially busy, loud exhibition environments.

Future work

The responsibility for addressing accessibility in GLAM-based immersive experiences should not fall only on blind and partially sighted people. Thus, this toolkit offers guidelines which are designed to empower the GLAM sector and those responsible for developing such immersive experiences; thus, accessibility can be incorporated as part of the design process. XR experiences in a GLAM context can enhance existing exhibitions and spaces, and such installations are becoming more commonplace as hardware and software becomes more affordable, therefore it is important these experiences are as accessible as possible. This requires input from people from the GLAM sector, those with lived-experience, developers, specialist charities, policymakers, and academia; by working together, we can achieve this goal.

1 Analysing the existing literature

1.1 Introduction

People with visual impairments are often interested in accessing museums, galleries, libraries and archives (Asakawa et al., 2018). However, people with visual impairments[1] are often unable to do so because of challenges related to access, navigation in the buildings and difficulties accessing artwork or other offerings (Ahmetovic et al., 2021; Asakawa et al., 2018).

Research into the interactions between visually impaired people and the GLAM sector highlights various strategies to enhance accessibility and inclusion through the use of AR and VR technologies.

To make art exploration more accessible, there are guidelines for verbal descriptions and accessible art tours (Rector et al., 2017). In the US, Art Beyond Sight creates accessible art programmes and educational materials to help museums generate accessible programmes (Art Beyond Sight, nd). Larger museums such as the Museum of Modern Art (MoMA) have access programmes that can provide recorded audio guides and touch and description tours for visually impaired people (MoMA, nd). At the Seattle Art Museum (SAM), there are a variety of visual aids for loan such as magnifiers, EnChroma colour blind glasses, smart phones and wired headsets, as well as some braille labels and verbal descriptions of select objects (SAM, nd). There used to be in-person accessible art tours that provide detailed verbal descriptions and tactile art exhibits, but as of date of publication they are no longer offering these tours (SAM, nd).

While larger museums tend to have some offerings for visually impaired people, they are not as readily available in smaller museums. Even in larger museums, accessible tours are often infrequent, such as only once per month and must be booked in advance (MoMA, nd).

Previous research has focused primarily on initiatives to translate visual art into tactile content more accessible to PVI. More modern studies emphasize the importance of multi-sensory experiences, including both tactile and audio elements to enrich the museum visit for PVI.

[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.

1.2 Research questions

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

- What existing research has been conducted for accessibility to the GLAM sector for people with visual impairments?
- What studies have been done into making virtual reality, augmented reality and/or extended reality experiences in the GLAM sector more accessible for people with visual impairments?
- What key takeaways from these studies could be implemented into future GLAM sector exhibitions to make them more accessible and enjoyable for people with visual impairments?

1.3 Methodology

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

- Blind, partially sighted, visual impairment
- Immersive, immersion
- Game, videogame
- Virtual Reality, Augmented Reality, Extended Reality
- VR, AR, XR
- Accessibility
- Gallery, archive, library, museum
- GLAM
- Multisensory

1.4 Results

1.4.1 Multi-Sensory and Polysensory Approaches

Many studies have found that a multi-modal approach significantly enhanced the museum experience for PVIs. This includes multiple offerings, such as the creation of leaflets to accompanying exhibitions in easy-to-read fonts, audio descriptions, and pre-guides co-created with individuals with lived experience to enhance the museum experience (Pawłowska et al., 2024; Długosz, 2022). One study explored the use of 3D-printed replicas of cultural artifacts, which were evaluated by blind and partially sighted users (Bruns et al., 2023). Participants preferred stereolithography for its aesthetic quality and fidelity, indicating a strong interest in tactile engagement with museum objects (Bruns et al., 2023).

Researchers have also used technology to aid in the creation of tactile reliefs of images and paintings (Reichinger, et al. 2011; Hernandez and Barner, 2000). However, these are often difficult to acquire, have limited availability and are often abandoned (Rector et al., 2017). Sound has been used to convey edges of items in pictures using phones, iPads and Wii remotes (Yoshida et al., 2011; Goncu et al., 2015; O'Neill and Ng, 2008). Sound has also been used to convey colours in images and paints (Cavaco et al., 2013; Meijer, 1992; Pun et al., 2010). However, these projects present sounds as a literal translation of the colour which is often not pleasing to the ear (Rector et al., 2017).

In order to appeal to multiple senses, many museums utilise AR and VR applications as well as tactility, or a combination of these.

1.4.1.1 Augmented Reality and Apps

Researchers in Tokyo conducted studies at Miraikan – The National Museum of Emerging Science and Innovation with visually impaired people (Wang et al., 2024a; Wang et al., 2024b). One study compared two smartphone-based guide systems for navigating and understanding exhibits in the museum (Wang et al., 2024a). One app provided direct interaction with turn-by-turn navigation and screen reader-controlled audio description, while the other offered immersive experiences with spatialized sound navigation and automatically playing audio content. The users wore an iPhone 12 Pro housed in a hanging case around their neck with the camera facing forward. Bluetooth open-ear headphones were used to allow simultaneous system audio and environmental sound. There were seven participants in the study who had no vision, used white canes, and had not visited the exhibition previously. Users tended to prefer the immersive spatialized sound for navigation. For gaining information, users liked the autoplay of the audio but wanted on-demand direct control. The touch instructions were inadequate for aiding interactions with tactile exhibits. In this study, a hybrid system, adding direct interaction to the immersive experience and adaptable to both environment and user requirements was found to enhance the museum experience for VIP (Wang et al., 2024a).

Researchers at the University of Lodz conducted several studies around disability access to local museums (Pawłowska et al., 2024). The "Friendly City" Project supported the independence of people with visual impairments in the use of the public transport network in Lodz, including applications focussed on location information and local architectural monuments. The ongoing project aims to develop an application that makes it easier for the visually impaired people to navigate around Lodz. The researchers consulted with members of the Polish Association of the Blind (PZN)—branch in Sieradz, the Lodz District—Lodz—Gorna Circle and the Municipal Circle No. 3 Lodz-Centrum. The consulting group was varied in terms of age, eye-sight loss history and educational background.

The participants were interviewed about the development of audio descriptions. The major findings were a preference toward technical terms (with regards to architecture) in simple two-to-three-word explanations, and a glossary of more difficult terms. During the study, there were several walks around the city to look at architecture with a mixture of PVI and sighted participants. Sighted participants wore eye trackers to show where eyes went based on the descriptions. In the next stage of refining the descriptions, both versions (the one involving the Polish Association of the Blind, and the one based on the eye tracking results) were read to visually impaired consultants. Their feedback on the usefulness of the audio descriptions was collected through a survey prepared by University of Social Sciences and Humanities in Warsaw (SWPS) staff.

Another of the University of Lodz projects created an app for a private Factory Museum to help users navigate the facility with guiding markers that enabled PVIs to independently explore urban spaces and exhibitions by directing them to specific locations and describing the appearance of the spaces and objects. This was co-designed with and tested by PVIs. Unfortunately, funding ran out and it was not viable to take the prototype forward for the private museum (Pawłowska et al., 2024).

Australian researchers assessed the effectiveness of commodity technology solutions and co-designed museum experiences in the Victora & Albert museum's Mary Quant and Elvis exhibitions (Nagassa et al., 2024; Butler et al., 2023). The solutions were co-designed with several blind and low vision participants. Both tactile and sensory versions of the museum exhibits were created for visually impaired people. They found that the placements of quick response (QR) codes, Near-field communication (NFC), voice recording buttons and touch-triggered electronics were immediately accessible and available to visually impaired people (Nagassa et al., 2024). This study found that recognising the variety of needs and preferences of PVIs and offering multiple, customisable solutions that can be adapted to their needs was key to the success of the study (Nagassa et al., 2024). The researchers advised that when implementing commodity technology in museums, solutions should be intuitive and easy to use, and pre-visit and post-visit access can help with immersion and accessibility to enhance visitor experience.

Alongside Microsoft, American researchers developed Eyes-Free Art, a design probe to explore the use of proxemic audio interfaces for interactive sonic experiences with 2D artwork for visually impaired people (Rector et al., 2017). The proxemic audio interface allows users to move closer and further away from a painting to experience background music, a novel sonification, sound effects and a detailed verbal description. The level of detail increases as a person moves closer to a painting, moving from background music, changing music, sounds and verbal. The study was held with 13 people with visual impairments who were able to interact with five paintings in a live installation of The Oregon Project, developed with a visually impaired artist. Participants appreciated the interactivity of the proxemic interface, both in the ability to move among zones and the ability to use their hand to explore more deeply within a given zone. Interaction techniques and sounds gave users a way to have a more immersive art experience and allowed them to spend as much or as little time with the artwork as they wanted (Rector et al., 2017).

MusA is an inclusive mobile app aimed to provide interactive artwork descriptions to low vision museum visitors in AR (Ahmetovic et al., 2021). The researchers found that while audio descriptions were important for people with visual impairments, they were rarely ever interactive. The study had two iterations. The first was to present descriptions in an interactive way that would be accessible to people with low vision. The app recognises the outlines of objects in different artworks and partitions the descriptions into chapters that the user can skip, pause, resume and go to previous or next chapter. The user can tap on the artwork on their phone in AR to select visual elements and play the associated chapter (Ahmetovic et al., 2021). The first study was conducted with four people with low vision at the Pinacoteca de Brera in Italy. In the first study, participants cited issues with contrast in the artwork, holding the phone for long periods of time, rotating the device, and the need for a zoom function (Ahmetovic et al., 2021). The second study implemented changes into the prototype including audio and haptic cues, virtual mode allowing the phone to be pointed down after an artwork is recognised, zooming in VR mode, and high contrast contours.

The second study had 7 participants with low vision. The majority of participants found the AR experience more engaging than traditional audio guides. (Ahmetovic et al., 2021). However, people with highest degree of visual impairment did not find it helpful.

1.4.1.2 Tactility

The Bento Museum project at the Tokyo Museum of Emerging Science (Miraikan) developed a 3D interactive map that allowed visitors with visual impairments to explore museum layouts and exhibitions through audio-tactile interactions (Wang et al., 2024b). It was named the Bento Museum project because the 3D interactive map is a layered, stackable museum map similar to the layering and stackable nature of a Bento box. The Bento Museum was tested with 12 visually impaired people who had never been to the museum before. After interacting with the 3D interactive map, users showed improved spatial awareness and confidence in navigating the museum (Wang et al., 2024b).

The Art from Lodz Against the Background of European Art project used typhlographics (graphic reliefs made using the thermoforming technique) that depicted buildings, architectural details, and other related aspects of Lodz and European architecture. published architecture books in Braille and enlarged font to help people learn about architecture, culture and history (Pawłowska et al., 2024).

An Australian project at the V&A museum investigated accessible gallery experiences for VIP for the Mary Quant Exhibit and, after the success of the first exhibit, then the Elvis exhibit (Butler et al., 2023). They provided an array of tactile interactions for the Mary Quant exhibit, including A5 tactile cards with Mary Quant outfits with large print and braille info on the cards provided to individual users; 3D printed interactive models of significant Quant poses co-designed with a visually impaired collaborator; small replicas of Quant outfits on Barbie dolls; paper doll laminated figures in poses; life-size mannequins with interactive outfits; and scents associated with Quant. These were very well-received by visitors who felt immersed in the exhibit.

The following Elvis exhibition attempted to utilise tactility for visually impaired users through the creation of 3D printed replicas of various places Elvis had lived; a refreshable tactile display (Graphiti) for PVI visitors to follow Elvis' dance move shapes on an interface of moving pins; replicas of Elvis' mothers outfits; and tactile fabric cards (Butler et al., 2023). The Elvis exhibition was less well-received. Users felt that the tactile cards did not make sense with that particular exhibition and there was limited interaction with the refreshable tactile display. This study puts forward a framework for inclusive galley experiences that include weighing up Resources, Interpretation, Programming and Experience (Butler et al., 2023).

Some South Korean studies utilised multisensory outputs based on the colours of a 2.5D representation of a painting (Cavazos Quero et al., 2018; Cho, 2021). The user could explore the painting by touch that would trigger localized sound, scent, verbal, audio, wind and light or heat feedback events to convey spatial and semantic information. The prototype was tested on six visually impaired people. The prototype had positive responses, but some users were unable to identify all of the colours because of a high cognitive load (Cavazos Quero et al., 2018). It was determined that the prototype is not necessarily scalable for large museums (Cavazos Quero et.al, 2018).

1.4.2 Gesture Based Interactions

Reichinger et al. (2018) created a gesture-controlled interactive audio guide for tactile reliefs of paintings in museums. Low-cost depth cameras (Intel RealSense F200) operated directly on relief surfaces and offered users the ability to interact with explorable, location-dependent verbal descriptions. The prototype was tested with 20 PVI users with a mix of sight loss (Reichinger et al., 2018). Most users liked the direct interaction with the finger, intuitive interface, simplicity, combination of 3D touch and simultaneous audio, the in-depth descriptions, and that the texts were short highlighting a low cognitive load. They also noted that independence from human guides gave users the freedom to explore paintings without time pressure. The ability to make the interactions and descriptions as long and detailed as they wanted was also highlighted as a success.

Bartolome et al. (2019) similarly explored the creation of a prototype 2.5D tactile representation of artwork where tactile gestures and voice commands would trigger audio descriptions and sounds. The study had eight participants who were visually impaired (Bartolome et al., 2019). The prototype consisted of an acrylic box with a 2.5D model of the visual artwork placed on the top surface. The model is 3D printed and coated with conductive paint and connected to the control board. All the components, including the microphone are housed inside the box. Touch gestures are recognised by a *BareTouchConductiveBoard,* an Arduino-based board with touch-sensing inputs and a computer for speech recognition.

The users agreed that the voice controls could be improved by the use of a human voice, instead of the robotic TTS one, which would suit better the artistic mood and express emotion better on the audio descriptions. They also mentioned it would not only improve the artistic engagement quality of the descriptive audios, but that it also would make the initial instructional audio easier to understand and, as a result, the system easier to use. Users wanted to know that the computer understood their input and also suggested a cooperative mode for sharing the experience with others (Bartolome et al., 2019).

1.5 Conclusions and recommendations

People with visual impairment are interested in having more control over their museum experiences (Asakawa et al., 2018). Several studies highlight the importance of indoor navigation of GLAM spaces (Asakawa et al., 2018; Nagassa et al., 2024; Wang et al., 2024a; Wang et al., 2024b).

Detailed audio content is necessary (Asakawa et al., 2018). Enriched audio descriptions tended to improve user experiences (Wang et al., 2024a). Users did not enjoy the monotone delivery of the automated voice-over, preferring instead natural narration and ambient sounds (Wang et al., 2024a; Asakawa et al., 2018; Bartolome et al., 2019). Navigating through descriptions, being able to choose the depth and breadth of the description, and ability to skip sections were highlighted as important user preferences (Asakawa et al., 2018; Ahmetovic et al., 2021).

Participants expressed a desire for more guided tactile exploration (Berube, 2023), but the tactility should match the theme of the exhibit (Butler et al., 2023).

Adaptability to user needs was a key finding of many studies (Wang et al., 2024a; Nagassa et al., 2024). Many users appreciated immersive experiences in the museums but also desired direct controls for autonomy (Wang et al., 2024a; Asakawa et al., 2018).

Key findings from the V&A exhibitions include recognising the variety of needs and preferences of PVI and offering multiple, customisable solutions that can be adapted to their needs (Nagassa et al., 2024). Solutions should be intuitive and easy to use. Pre-visit and post-visit access can help with immersion and accessibility of content to enhance experience.

Despite advancements, challenges remain in fully accommodating visually impaired visitors. The reliance on visual-centric experiences in museums continues to limit access, indicating a need for ongoing research and development of anti-ocularcentric approaches to foster inclusivity (Berube, 2023).

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 professionals in the game development and cultural sector. Seven 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. Insights were sought from game developers specifically to identify best practices in their work that mapped across to public exhibition development.

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 PVI[2]. Specifically, those were:

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

While these motivated the content of the consultations, insights were also sought on attitudes to XR use and experience accessibility from both developers and players, opportunities for professional development

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

and resources for upskilling and on the impact of accessible experiences.

2.3 Methodology

2.3.1 Process

A structured interview was carried out with seven 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. Participants all consented to being on-the-record.

2.3.2 Practitioners consulted

- Bel Sculley, Access Manager at The National Portrait Gallery, London
- Professor Geoffrey Belknap, Keeper of Science and Technology at National Museums Scotland
- 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 visual 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?
4	• 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

Please note, in some instances, the term “blind” has been used rather than "PVI" because “blind” was the phrase used by interviewees.

2.4.1 RQ1: What established and emerging practices are employed by practitioners in the GLAM sector to enhance the accessibility of VR experiences for PVI?

2.4.1.1 Multi-sensory elements

Geoffrey Belknap described the challenge of accessible VR and wider extended reality as “intentionally and explicitly immersive technologies that require, to a large degree, either sight or hearing”.

Practitioners highlighted that an effective avenue for enhancing the interactivity of experiences, that also widens access for PVI, is to incorporate multi-sensory elements. Bel Sculley described how “all of our senses should be triggered” while “experiencing new ideas and art”, particularly smell which is “very closely aligned with memory.” Bel described the inclusion of tactile sensations to guided tours enhancing the art-appreciating experience for PVI. This included handling fabrics that matched the clothes of the subject and tasting foods that were featured. Cari Watterton described considered audio design and haptic feedback in games, which can also be used in GLAM experiences. Adding a non-visual form of feedback, she said, was a “very easy way to add a layer of accessibility” in games, that “adds to a more full and complete world”.

Specifically for VR and related XR technologies, haptic design (typically motor-induced vibrations in controllers) is seen as an opportunity to provide greater sensory feedback. High-definition haptics, increasingly common features in newer VR headsets such as the PSVR2 headset, were brought up by several of the game developers interviewed as an exciting new tool. These new devices “allow users to feel digital environments and create more meaningful interactions” according to Sky Kim.

A misconception of VR is that it is a purely visual medium; many experiences use 360-degree, or spatial audio to enhance immersion. In providing directional sound cues, these devices can react to movement to adjust the soundscape and facilitate a great spatial awareness. Katie Goode emphasised how effective this spatial audio can be for PVI, as it allows them to act with greater accuracy.

2.4.1.2 Design for the spectrum of visual impairment

Bel Sculley explained that considering “the blind community” as a single entity is a common mistake made by those trying to make experiences accessible. Instead, they are “a group with a diverse range of different needs and lived experiences”. There is an acceptance that accessibility interventions will never work for everyone, and instead the mission is to “create programming and resources that service as many people as possible”. And this is echoed by the videogame development community, with Cari Watterton explaining it is currently impossible to “make a game that is 100% accessible to everybody”. Geoffrey Belknap described how while the ideal is to have a single solution for all levels of visual impairment, it is likely that solutions for individuals who are partially sighted, and those with no functional vision are entirely different.

For those who are partially sighted, GLAM practitioners explained the most effective support is to have large print for any text and for maps, and to consider the positioning of text. Again, games practitioners shared these considerations. In what Jamie Bankhead described as their “early baseline”, they explained that “large and scalable text, high contrast UI and colourblind filters” are included in any project they work on. Jamie continued to explain that, when testing, they consider what UI elements look like under various lighting conditions and against different backgrounds. Katie Goode similarly described how the aesthetic of their games is centred on readability: “when we designed our art style, very in the front of our mind was how readable objects are. So, we've got super crisp black outlining to things.”

In the GLAM space in particular, it is important to be considerate of the assistive technology that is being used, and what technology is no longer being used. Bel Sculley explained how common screen readers were amongst PVI and the importance of being considerate of the way in which those tools work. However, they also noted that PVI tend to be older, and therefore less likely to take up new technologies. Due to this they offer their own form of assistive technology but have found the raise-button audio descriptive tours (tours which use handsets with tactile indicators) to be less successful than they expected, with very few visitors using them because they are unintuitive and uncomfortable.

2.4.1.3 Applying general accessibility principles and guidelines

A fundamental established practice, as highlighted by practitioners, is direct and early engagement with PVI, user groups, and advocacy organisations from the very beginning of any VR development project within the GLAM sector. This co-production is viewed as the method by which, as Bel Sculley put it, “great things happen.” They continued in saying “the only way to truly know what people with access needs can and can’t do, or like and don’t like, is to work with them”. Which stands in contrast to both making assumptions, and simulating access barriers. The latter of which was a commonly derided bad practice noted by practitioners, despite being disappointingly common in both the games and GLAM sectors. Involvement of PVI in testing and experience development is discussed in full later.

Alongside direct user engagement, relying on existing general guidelines is another common practice. In gaming, there are general game accessibility guidelines, as well as platform specific guidelines, which Cari Watterton explained was where their efforts began on a new project “to help guide us and steer us on the right path”. These guidelines, like the Game Accessibility Guidelines (2012) which Katie Goode contributed to, are common in games and widely applicable to GLAM experiences. Jamie Bankhead described the internal wiki that Konglomerate Games have built up that includes several accessibility guidelines. GLAM institutions also draw their own internal guidelines and principles for exhibition design, covering practicalities like text size, display height and colour balance. The minimum requirements for accessibility are legal ones, such as the Equality Act 2010, which states everyone must be able to engage with public platforms, however best practice will go far beyond this.

A helpful approach is to focus on the barrier, rather than the disability. A barrier is an unintentional challenge arising from a mismatch between a task and someone’s capability, whereas a disability is a personal circumstance. As Cari Watterton described, 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.

2.4.2 RQ2: What are the key challenges and practical considerations encountered by GLAM sector practitioners when developing and implementing accessible VR experiences for PVI?

2.4.2.1 Resource and budget limitations

Geoffrey Belknap said that while VR and wider extended reality technologies are “a great option for bringing in and engaging our audiences with new ways of experiencing immersive worlds”, they are also “very cost and labour intensive.” As a result, Geoffrey explained that XR interactives are implemented on an ad-hoc or bespoke basis, rather than part of a broader strategic initiative. Further, Bel Sculley explained that maintaining and updating VR experiences to reflect regularly changing exhibitions was a substantial resource challenge which they do not have the capacity to do in-house. Many heritage institutions do not have a specific accessibility budget.

The direct costs associated with accessible VR development are multifaceted. Essential user testing and feedback gathering from PVI involves planning, collaboration with partners or charities, and the organisation of these engagements. All of which Jamie Bankhead explained were highly expensive and often beyond the budget of smaller development studios. Similarly, Katie Goode described efforts to maximise accessibility while keeping within budget constraints. Audio design must be emphasised, and many small studios won’t have a dedicated audio designer. Similarly, voice-over is required for all text, and possibly for environment description, which is expensive in the first instance and more so when it must be localised to several different languages. Sky Kim described cloud-based AI alternatives for text-to-speech which could serve as voice over, but these require costly modern hardware.

Avenues to make VR development more practical, and to keep costs low on accessible VR development projects, include having internal testing and a database of internal data which can be used for evaluation. Alternatively, Katie Goode explained how they use public events for evaluation, or a group of dedicated fans with lived experience of impairments. When providing experiences at home, like VR tours that allow people to experience exhibitions from their living rooms, one must consider the access to VR that PVI will have. Katie explained that due to the intersection between accessibility needs and low-income households, developers should be mindful of the hardware and physical space that might be available.

2.4.2.2 Technical constraints & practical limitations

Technical constraints are the main reason that, as Cari Watterton expressed, it is impossible to make VR experiences that are 100% accessible to everyone. However, as an emerging technology, innovation is making VR more useable and more accessible. Sam Watts described how early VR hardware presented its own technical barriers, including cumbersome setups, the need for expensive high-end PCs, and that the devices themselves were cumbersome and heavy. Worse, the technology for rendering to screen was poor, which lead to many people getting nauseous from the experience. Sam went on to explain how that belief, that VR makes you nauseous, continues, despite his personal experience of testing VR with thousands of people in person and having “only one or two” incidents where someone had to take the headset off.

The technical performance of capabilities of VR hardware, including limited processing power, screen resolution and refresh rates, impose constraints on rendering complex content or high-detail assets effectively. Sam Watts described newer devices which can improve the experience by changing the picture based on focal depth, but these are “ridiculous, expensive and heavy”, while that technology is coming, it is not going to be widely available soon.

Interacting with existing simple interfaces in VR, like menus, is a real challenge for PVI. Sky Kim explained how the number pad PIN entry used for authentication on some headsets was not possible for PVI, stopping them from using the devices at all. This highlights that particular attention should be given towards creating accessible interfaces which are customisable.

The rapid evolution of the technology will make it more broadly accessible. Additionally, innovations in AI and cloud-based computing will improve the capabilities of the headsets. However, the rate of advancement can make old accessibility solutions obsolete. Ways to address this include graceful degradation across devices, matching the experience to the device’s capabilities.

2.4.2.3 Dynamic, physical environments

The development and implementation of accessible VR experiences often intersect with considerations related to the physical environment and the user’s interaction with it. Bel Sculley highlighted often overlooked considerations such as the time of year effecting the light conditions which PVI are significantly affected by, and others fail to account for. When organising sessions for accessibility programs, these tend to be during office hours, which does not permit those working to attend.

A particular challenge to the GLAM sector is navigation of the space for PVI. The regularly changing nature of museum collections make this worse. Bel explained that a VR representation of the gallery being out of date following a new layout can cause upset and that “we have had to be very explicit in saying that the tours aren’t exactly representative of what’s in the galleries”.

VR exhibitions, like all exhibitions, require interpretive materials and possible physical interactives. These must be considered in conjunction with the VR itself, in terms of view height, text size and colour contrast. Geoffrey Belknap explained how physical aids like tactile maps and braille interpretation requires careful thought regarding placement and integration within the physical gallery flow. This is only made more important with potentially hazardous VR users navigating the space without full awareness of their surroundings.

In public settings there are issues arising from the hardware being used by multiple people in one day. Beyond the likelihood of breakages and theft, there are hygiene considerations for which there is no easy answer. Immersive alternatives to VR include augmented reality, where images of the real world are overlaid with extra elements, or Pepper's ghost, a holographic-like illusion technique used in theatre, which Katie Goode highlighted as affording shared augmented reality experiences without individual headsets.

2.4.3 RQ3: How are the needs and perspectives of PVI incorporated into the design, development and evaluation of VR experiences within the GLAM sector?

2.4.3.1 Measuring with PVI

Measuring the accessibility of VR experiences for PVI involves direct engagement and gathering feedback from individuals with lived experience. This is true in games as it is in the GLAM sector. While accessibility guidelines offer a good starting point for all development, unique challenges will arise from any given project and only end-user testing can reveal the full extent of them. We were told that game 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 (2020) to get a deeper understanding of PVI's experiences. Bel Sculley described a more "organic" process for testing where strong relationships are built with user groups that can provide open and honest feedback.

Practical constraints, like costs, may preclude testing of every aspect of an experience with end users. Sam Watts explained that sadly accessibility testing for “less represented or smaller segments” of the potential audiences is often the first things cut from a project to save money. In such cases, previous learnings can be used to inform design without needed to retest everything.

2.4.3.2 Structures for collaboration

Practitioners emphasise that collaboration with PVI communities is an essential element of the development process for new experiences. Bel Sculley “would never create a new resource for people who are blind without working with them to develop it and test it.” Cultural institutions frequently establish these collaborations by working closely with charitable organisations that directly support different disability communities. This process typically begins with seeking recommendations for people with lived experience who can be involved in the development, through consultation, focus groups, or testing. The overarching aim is to engage communities through “collaborative and co-creative methodology”, says Geoffrey Belknap, ensuring input genuinely influences the work, as opposed to serving as a perfunctory review.

The value of building and maintaining relationships with PVI communities was consistently highlighted by all of those interviewed, with Cari Watterton describing the relationships they have built with specialist accessibility consultants during their time in the games industry. Specifically, how that led to more direct and addressable feedback. They described how these specialists can be brought on at an earlier stage of implementation without context of the full experience to course-correct from prototyping phases, whereas a layperson may struggle to evaluate the effectiveness of individual elements in isolation.

Development teams also gain crucial insights by engaging with critics who have lived experience of visual impairment or including team members who themselves face access barriers. For smaller teams, building these necessary feedback loops can involve fostering relationships with enthusiastic fans who can provide input on experiences in development, although this may not be representative of the broader PVI community.

2.4.3.3 Testing early

A consistent best practice highlighted by practitioners is the integration of testing with PVI and individuals with lived experience from the earliest possible stages of the development process. Geoffrey Belknap described the obvious lessons learned from their work with accessibility "Do it early and do it in collaboration." The alternative, bringing in consultants late into the process, or "rubber stamping work one has already done", is far worse than the "actual, real opportunity for engagement" early testing provides.

Integrating feedback from the beginning helps shape the program or experiences effectively and saves significant effort and cost later on. For museums developing exhibitions, bringing in communities early allows them to discuss planned implementations and potential barriers, providing feedback that can directly inform redesigns and adaptions. One particular area where this is beneficial is ensuring suitability for modern technological aids that PVI use (e.g., screen readers).

The emphasis on early testing is shared in the game development industry. Where smaller studios are working with external partners who are subject matter experts, such as the work of Konglomerate Games, they will work with their partners to facilitate this testing. Bringing in experts can be expensive, so it is often charities and special interest groups who are collaborated with on serious games or short-term projects. On larger commercial projects there can be issues around privacy with consultants required to sign non-disclosure agreements (NDAs). Despite the practical limitations, the guiding principle remains that the earlier feedback from PVI is incorporated into the design and development process, the more accessible and inclusive the final experience is likely to be.

2.4.4 Further Insights

2.4.4.1 Public reception

The public reception of accessibility initiatives, particularly within the cultural sector, is generally reported as being positive. However, complexities arise in managing expectations and navigating broader societal discussions. For instance, accessibility work at institutions like the National Portrait Gallery has been very well received, and Bel Sculley notes that she has never encountered public sentiment questioning the effort invested in accessibility itself. Criticism, when it arises, tends to focus on aspects beyond their direct control, such as building limitations. Occasionally, it is also linked to broader discussions on diversity and inclusion efforts, which can sometimes be framed negatively (e.g., as "woke").

This general support for accessibility is partly attributed to the widespread nature of accessibility requirements, with increasing numbers of individuals having personal connections to someone facing barriers. Similarly, Geoffrey Belknap observes that while communities of practice may be initially sceptical, there is a broad desire for and appreciation of accessibility efforts from audiences, with a wide range of people viewing them as integral to understanding diverse perspectives and aligning with the cultural sector's core purpose to educate, inform and entertain.

An important consideration highlighted by the games industry practitioners was transparency in what will and what cannot be offered in terms of accessibility. Setting clear expectations can lead to disappointment, but it is important to maintain positive relationships with visitors and customers. Cari Watterton pointed out that there are common misconceptions about how easily accessibility features can be added, but this is very much not the case, the same is true in the cultural sector. Where gaming accessibility contrasts that of the cultural sector is in designed difficulty, which Katie Goode explained as the requirement for public experiences to be accessible from the outset. This is mirrored somewhat in games, as Sky Kim noted, with the common practice of accessibility features being enabled by default.

2.4.4.2 Emergent and future technological innovations

Practitioners see significant potential in emergent technologies to reshape accessible design for PVI, particularly AI and advanced Extended Reality capabilities. Bel Sculley expressed great excitement for AI's potential to "absolutely open up access", noting how assistive technologies have already revolutionised participation for PVI. This includes concepts like AI-powered glasses that can describe surroundings in real-time. Sky Kim highlighted further practical applications, such as new generative vision models paired with text-to-speech for environmental descriptions and modern systems capable of vision post-processing to support PVI with object highlighting. However, concerns were raised about the ethical considerations of AI's reliability and copyright implications, and Geffrey Belknap cautioned that AI usage in museums must remain human-centred to ensure the audience is being best served.

XR technologies are advancing in such a way that they may drive accessible design implicitly. Enhanced haptic feedback, standard in some newer VR headsets like the PSVR2, offer a "third sensory method" for deafblind communities. Jamie Bankhead suggested eye-tracking could allow for dynamic adaptation of visual elements based on a user's gaze, particularly helpful for people with macular degeneration. Spatial audio is another key element of virtual reality and is seen as having significant potential for aiding navigation in virtual environments.

Despite excitement, challenges persist. Cari Watterton noted that achieving 100% accessibility across all games is not yet feasible with current technology. And these advances in features often come with practical drawbacks. Large AI models are computationally expensive and can lead to high computing costs or the need for bulkier headsets to provide space for larger hardware capable of the advanced calculations required. Services like text-to-speech and large language models are increasingly being gated behind paywalls.

2.4.4.3 Learning and knowledge exchange in the field

Keeping up with accessibility best practice requires continuous learning and robust knowledge exchange mechanisms. This is true for cultural institutions as it is for the games industry. A common approach for this is formal training. Bel Sculley explained how they used disability awareness training, delivered by people with lived experience where possible. Although in-person sessions are more informative, the practicalities of asynchronous, online training materials are often preferred.

Another avenue for maintaining best practice is the upkeep of internal wikis for knowledge sharing. It is a significant piece of work to ensure that these remain up to date. Jamie Bankhead described what made up the wiki they use for accessibility, including industry talks, external guides, toolkits and databases. At larger companies there are often dedicated accessibility roles for fostering education and advocacy through workshops and dissemination.

Finally, a significant amount of learning comes on the job. Geoffrey Belknap explained “it's the work of doing that is the biggest and most significant training for staff”. The approach they outline is of formal training programmes providing general principles, but depth of understanding coming from the day-to-day interactions where solutions are implemented through direct communication with the communities involved.

2.5 Conclusions and recommendations

This consultation with practitioners underscores a shared commitment to advancing VR accessibility for PVI (Table 1).

Barrier	Suggested action
Resource limitations	XR experiences are both cost and labour intensive to develop. Furthermore, GLAM spaces also have tightly constrained budgets It is suggested that specific budgets related to accessibility are made available.
Treating PVIs as a homogenous group	People are unique and have different needs. Flexibility and customisation are encouraged wherever possible.
PVIs not used to new tech	This is a mutual dependency issue – arguably PVIs may not have had to the opportunity to use XR. Therefore, it is important to roll out accessible, intuitive XR experiences and encourage feedback.
Hardware limitations	Provide fallback controls or voice alternatives for input and feedback.
Testing with visually impaired users	Can be expensive and require lots of planning. Challenging for developers and those in the GLAM sector as this requires lots of organisation. Recruit blind and partially sighted participants as testers early in the development process via user panels and talk to specialist charities.
Limited access to hardware and physical space	Seated or static standing experiences are preferable, due to risk of collision with obstacles.
Interfaces can be challenging to use	Ensure interfaces are intuitive, accessible and have been tested with those who have lived experience to ensure they perform optimally.

Table 1 – overview of barriers developers and senior GLAM space staff cited when creating accessible experiences in the GLAM sector.

Effective practices centre on direct, early and continuous engagement with PVI communities, employing co-development methods from initial concept stages through to iterative testing. Multi-sensory design principles incorporating audio, haptic and tactile feedback not only enhance the degree to which experiences are accessible but improve their richness altogether. Adhering to accessibility guidelines and considering the full spectrum of visual impairment are also key. A beneficial mindset for developing accessible experiences is to consider how to overcome specific barriers rather than broader disability labels.

Hindering the advancement of accessibility in the cultural sector are the practical considerations of resource limitations. Technical constraints with current hardware and development tools have impacts on comfort and suitability of VR experiences for PVI, this is compounded by rapid obsolescence of software solutions or paywall restrictions. Finally, the dynamic nature of physical museums spaces adds a further layer of complexity when designing and maintaining accessible VR experiences.

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.

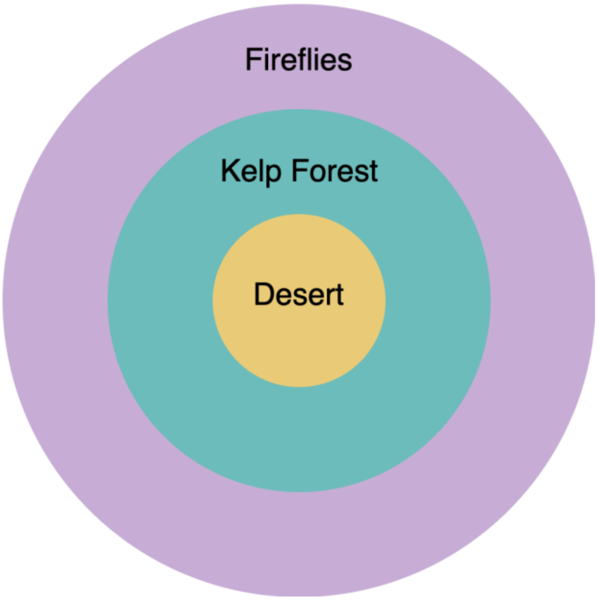

Figure 2 – representation of the three environments within Rhizoma VR.

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).

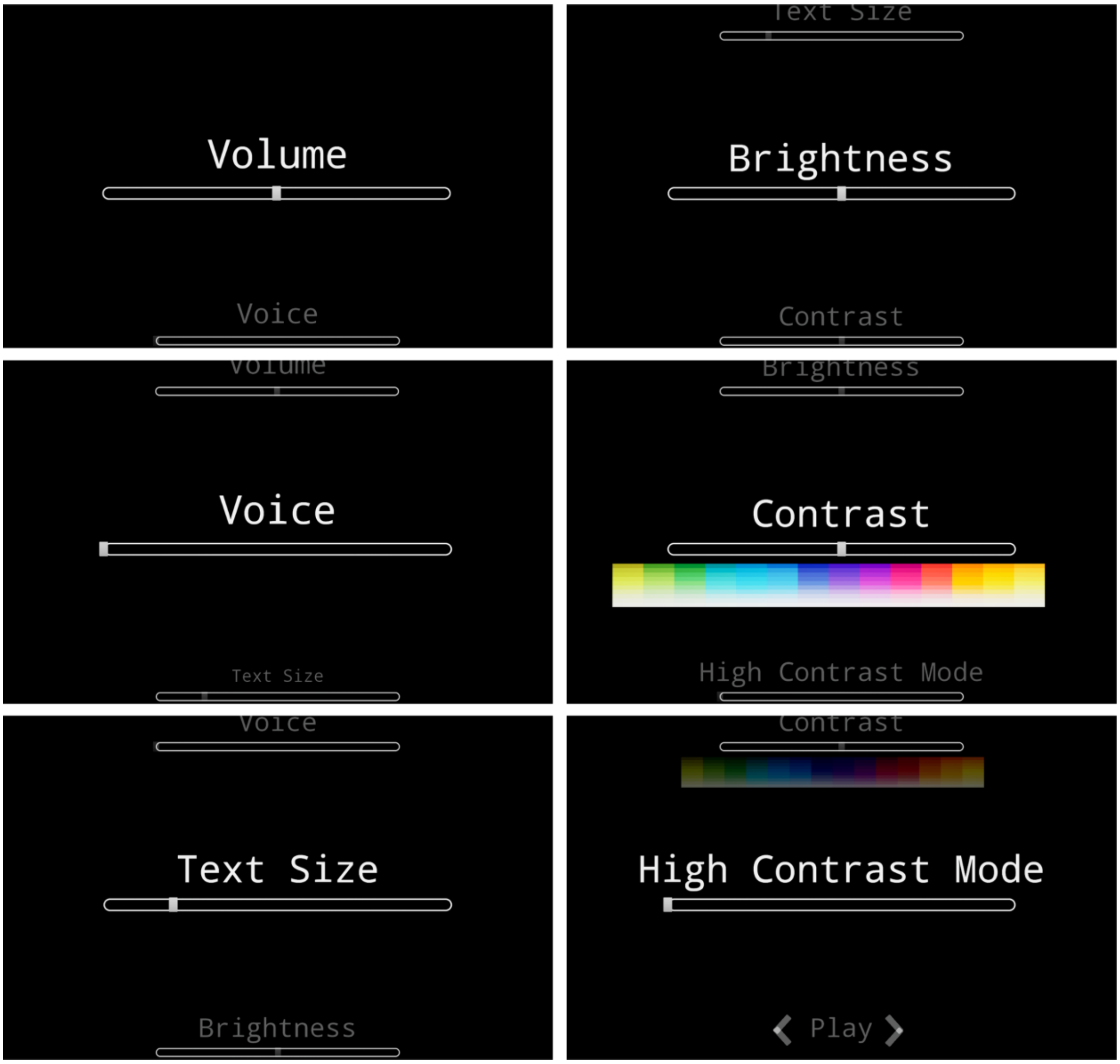

Figure 3 – From top to bottom, column one shows the volume, voice, and text size sliders. Column two shows the brightness, contrast, and high contrast mode sliders.

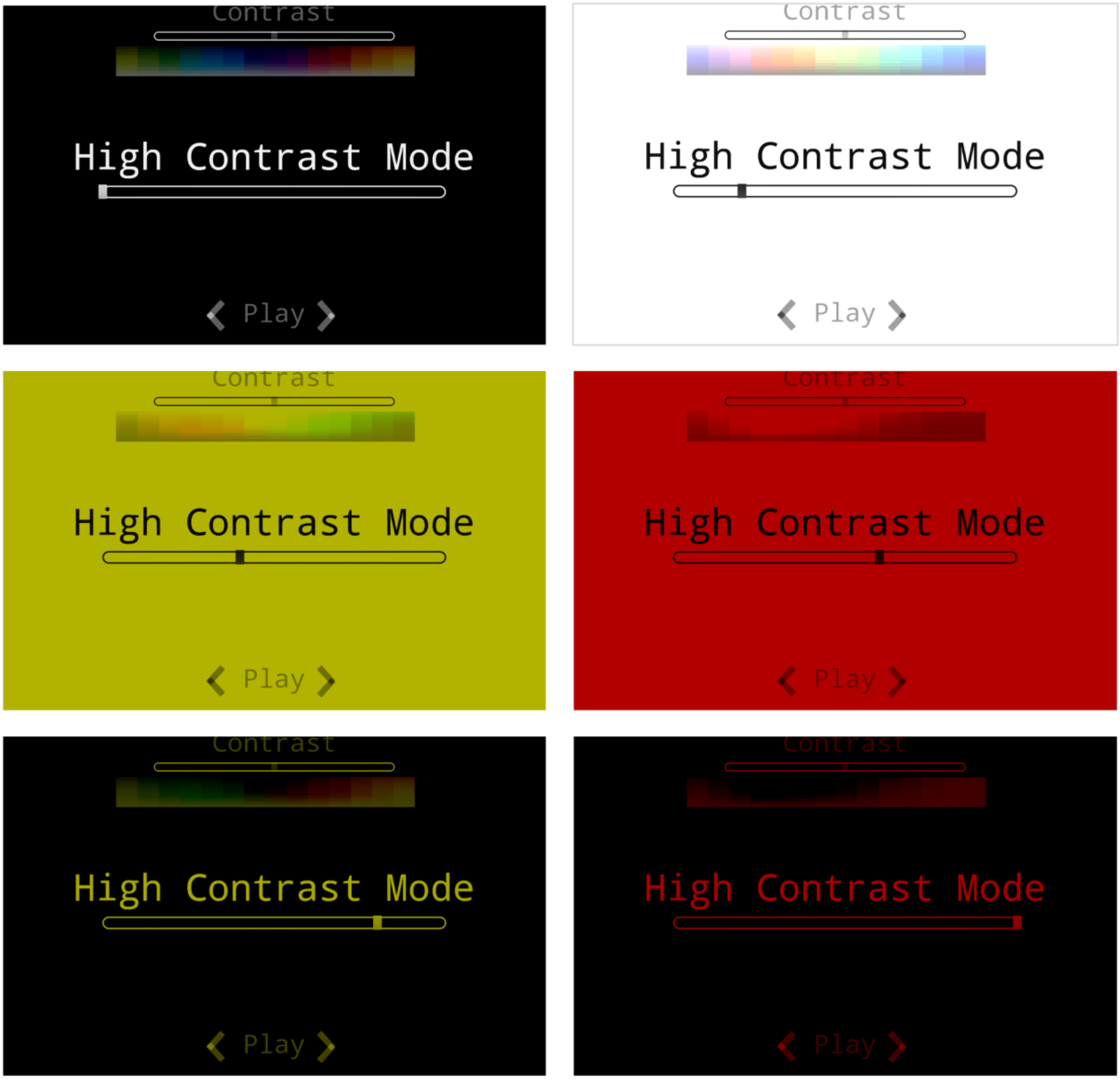

Figure 4 – Variety of contrast modes available in the Rhizoma VR experience.

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’.)”.

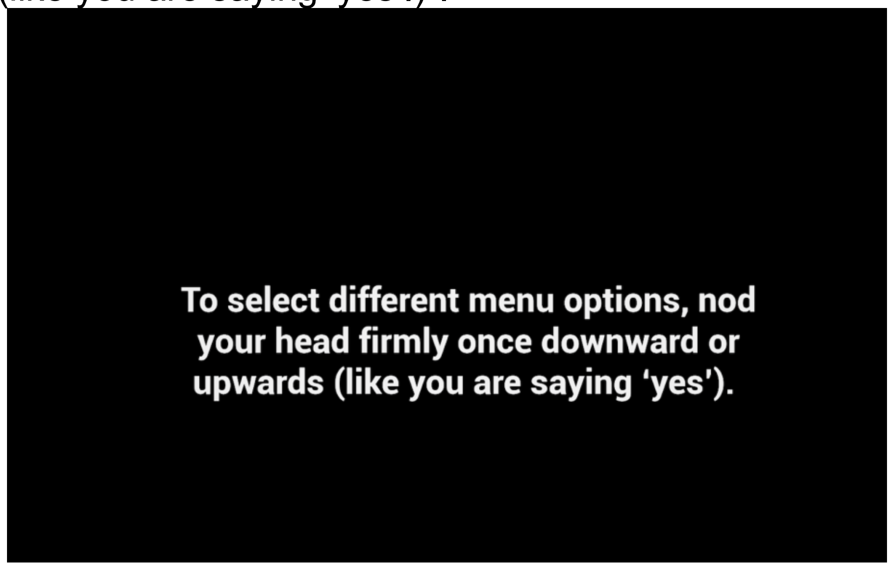

Figure 6 - the “yes” gesture screen.

- 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’).”.

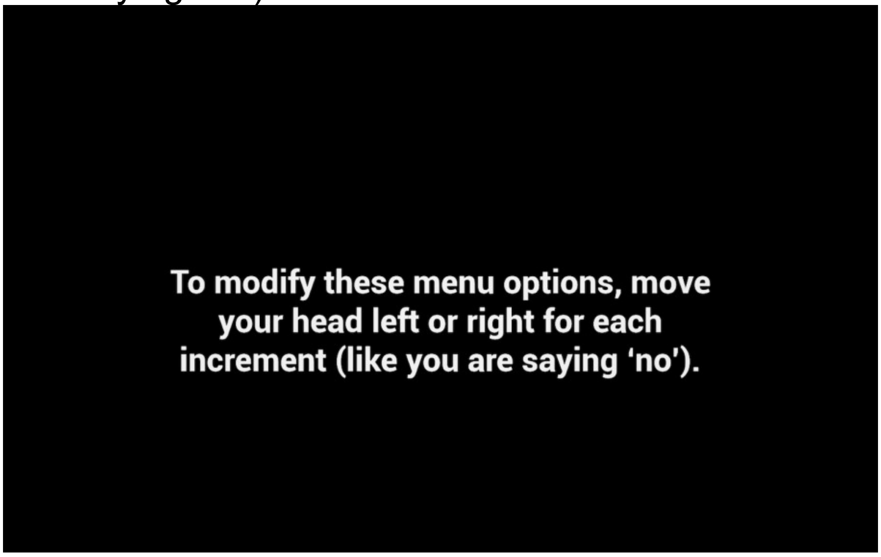

Figure 7 - the “no” gesture screen.

- 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.

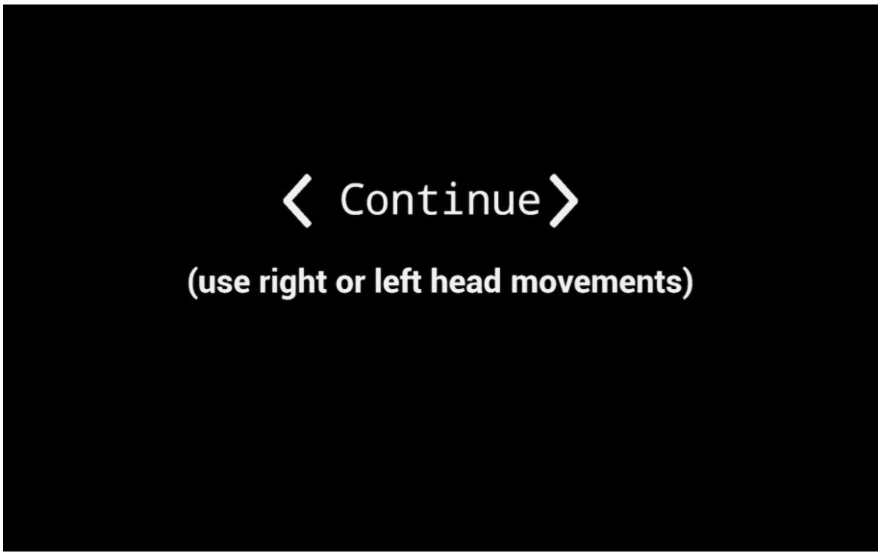

Figure 8 - the “continue” gesture screen.

- 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.

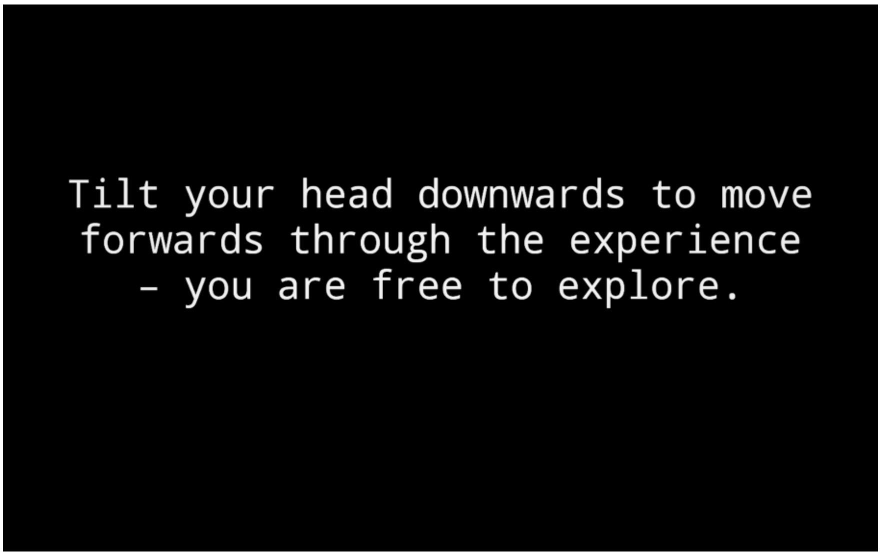

Figure 9 – explaining to the user how to move forward.

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: Rector et al., 2017.
Brightness	Brightness slider. Inspired by findings from: Ahmetovic et al. 2021.
Clear instructions	Rhizoma VR contains a number of instructional screens. Inspired by findings from: Pawłowska et al., 2024; Długosz, 2022.
Contrast	Contrast slider – slightly tweaks the standard contrast. Inspired by findings from: Ahmetovic et al., 2021.
Head gestures	Users can navigate using head movements; no additional controllers are required. Inspired by findings from: Reichinger et al., 2018.
High contrast	Distinct contrast options users can cycle through with a slider. Inspired by findings from: Ahmetovic et al., 2021.

Text size	Text size slider. Inspired by findings from: Pawłowska et al., 2024; Długosz, 2022.
Voice choices	Several realistic sounding AI-generated voices – option selected with a slider. Inspired by findings from: Wang et al., 2024a; Asakawa et al., 2018; Bartolome et al., 2019.
Voice over	Menu items, instructions, and zones within the Rhizoma VR experience are read aloud. Inspired by findings from: Rector et al., 2017; Pawłowska et al., 2024; Długosz, 2022.

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.

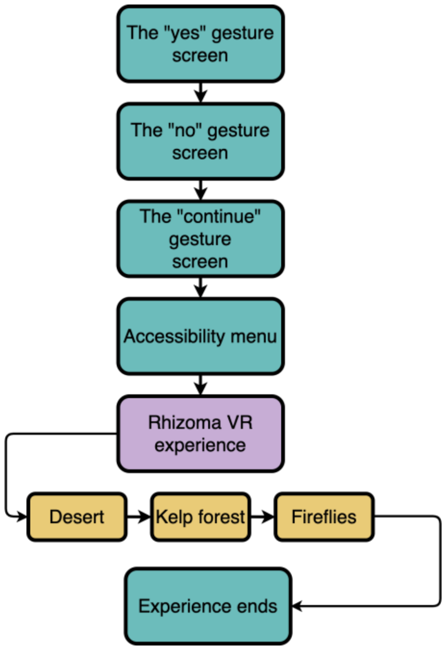

Figure 10 – flow diagram showing the different screens within the prototype.

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 visually impaired 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 around what 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 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 visual impairment, and assistive technologies used.

Following this, there were then some questions about gaming experience focusing on frequency of visits to GLAM spaces, 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 this was an aspect to consider (Cavazos Quero et al. 2018; Reichinger et al. 2018). 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 their overall experience with the SUS (system usability scale), before addressing some open-ended, free-text questions about their experience. To conclude the Rhizoma VR study,

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

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 visually impaired 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 visual impairment and use of assistive technologies

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

Level of visual impairment	Number of responses
Mild visual impairment (some difficulty seeing but manageable without assistive devices)	1
Moderate visual impairment (difficulty seeing even with corrective lenses, may use assistive devices)	3
Severe visual 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 visual 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 accessing GLAM spaces

When asked “How frequently do you visit galleries, libraries, archives, or museums?”, the majority of participants (n=6) visited a few times a year (other responses: n=2 visited weekly, n=1 visited monthly, and n=1 indicated they had visited these spaces in the part but had since given up. When asked “Have you faced accessibility challenges when visiting galleries, libraries, archives, or museums?”, the majority (n=7) indicated “yes”, with n=2 stating “maybe”, and n=1 stating “no”.

When asked to describe accessibility challenges in GLAM spaces, a number of themes were derived from the free-text responses.

4.4.2.1 Navigation

Navigation was cited as a key problem when accessing GLAM spaces. It was highlighted that several libraries have stepped access and no accessible toilets which makes visits challenging. Others stated help and guidance was required to navigate new spaces, and a particular challenge was identified with some exhibitions having a low level of light, obscuring potential obstacles and making it difficult to view artefacts.

4.4.2.2 Information provided

Several participants cited being able to consume the relevant information as being a challenge in GLAM spaces. Issues ranged from tour guides providing poor quality information, and not being able to set their own pace for the visit.

Many participants struggled to read signs and plaques as part of exhibits, which again was detrimental to their understanding of the exhibition and overall experience. Plaques being placed flat against the wall were a challenge, with one participant indicating these are easier to read if placed on a table.

4.4.2.3 Discrimination

One participant shared their experience with their guide dog not being allowed into particular places, and issue which the Guide Dogs charity is campaigning to address (Guide Dogs’ Communications Team, 2022).

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.

4.4.4.5 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.

4.4.4.6 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.

4.4.4.7 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.

4.4.4.8 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.

4.4.4.9 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.

4.4.4.10 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.

4.4.4.11 Suggested enhancements for people with visual impairments

A number of suggestions were received to help make VR experiences accessible for visually impaired 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 XR experiences more accessible.

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 visual 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.

Participants expressed several challenges they have faced when visiting GLAM spaces which can potentially be addressed by accessible XR experiences. These include the likes of improved navigation, well-lit objects or artefacts presented in the XR space, and being able to explore an environment on their own terms.

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

5 Concluding remarks

Overall findings from this report highlight the importance of co-creating XR experiences with BPS during development. 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 tactile aspects through haptics) and balancing concerns around cognitive overload.

Interviews with XR practitioners and senior GLAM sector staff revealed that whilst they already make use of existing guidelines around accessibility, they also seek to engage with BPS and ideally would like to co-create experiences. That said, practitioners still face many hurdles when developing XR experiences for the GLAM sector, whilst GLAM staff struggle to incorporate installations; these range from hardware and tooling limitations, constraints around resourcing, budgets, appropriate spaces (e.g., gallery layouts and navigation), and catering to a wide range of intersectional needs.

We augmented an existing VR experience, Rhizoma VR (previously exhibited in Dundee Botanic Gardens), 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 experiences.

Moving forward, it is essential that all stakeholders, including employees from the GLAM sector, those with lived-experience, developers, specialist charities, policymakers, and academia, collaborate to champion the creation and placement of inclusive XR experiences in GLAM spaces. This toolkit offers a rich source of information to support the GLAM sector and developers 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.
- Depth camera: a specialised camera which calculates the depth and distance of objects in a scene.
- Echolocation: a system where sound waves are reflected off objects to help determine their location. This can be simulated in extended reality environments.
- Gaze tracking: this makes use of eye tracking to determine where the user is looking.
- 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.
- Near-field communication (NFC): protocols which enable communication between two electronic devices. It has a range of 4cm or less.
- Proxemic audio interface: an audio interface which presents the user with different audio tracks or a different mix of audio depending on their distance from a particular object.
- Quick-response code (QR) code: a 2D barcode which can provide information when scanned with a mobile phone.
- Screen reader: assistive technology which interprets software interfaces into spoken audio enabling them to be perceived and operated by BPS.
- 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.
- Stereolithography: a process of using resin to create 3D representations of objects.
- 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 screenreader built into Android platforms.
- 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 screenreader built into iOS platforms.

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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.

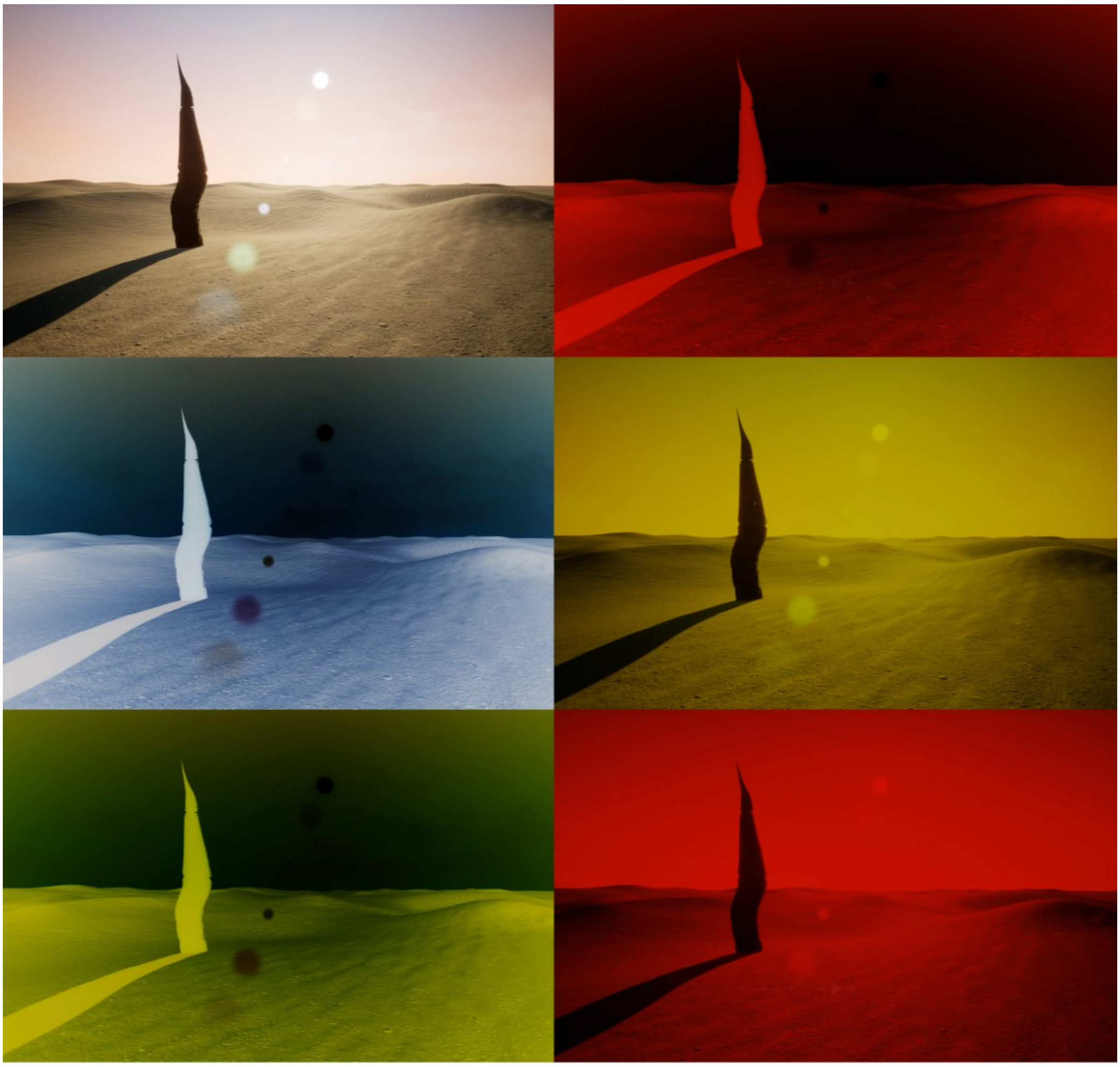

Figure 11 – The effect of different contrast modes on the desert zone.

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.

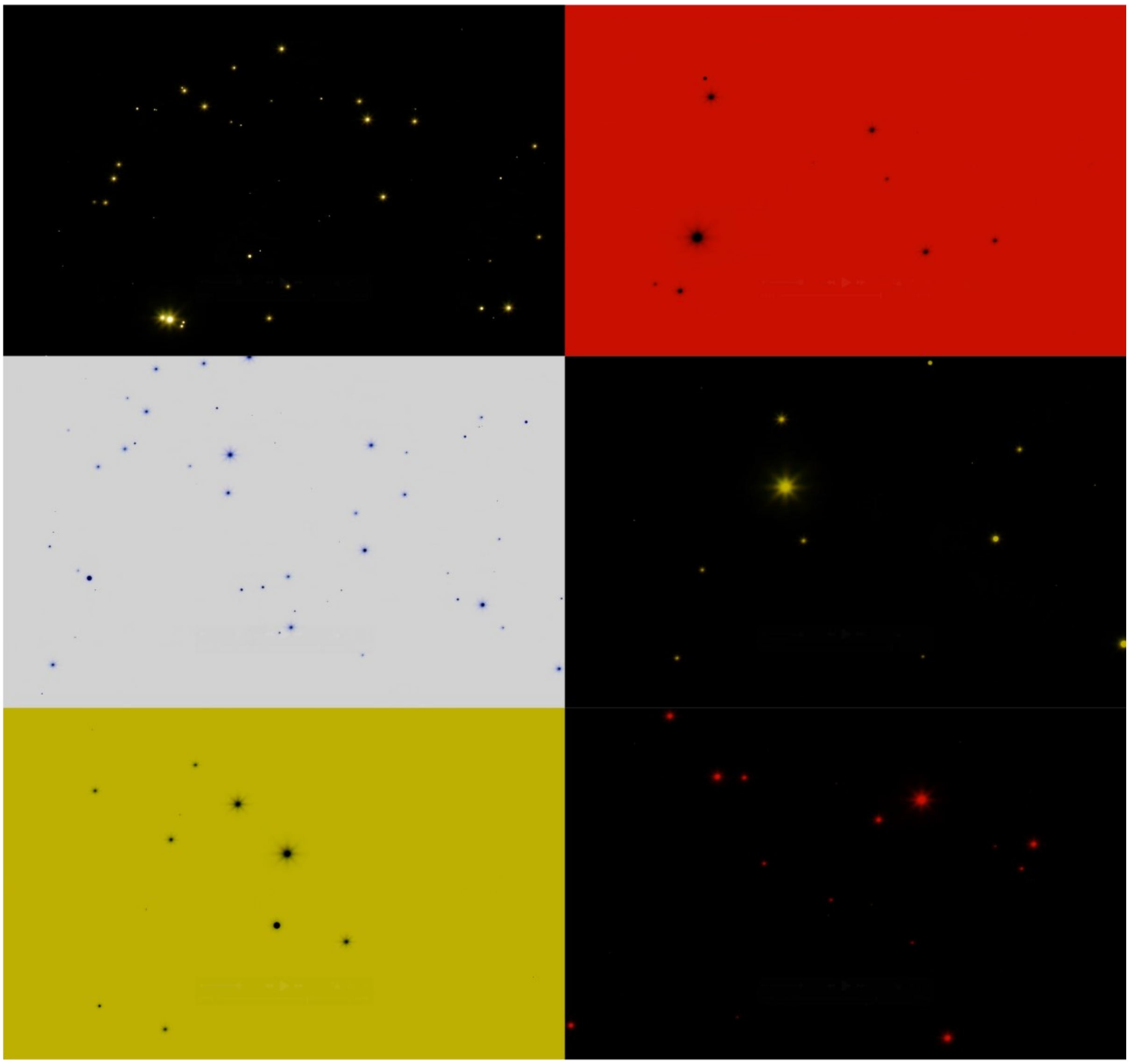

Figure 13 – The effect of different contrast modes on the firefly zone.

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
Note: results related to this section are presented in our gaming sector toolkit.

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

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>