Accessible Heads-Up Computing

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Abstract. Heads-up computing proposes a novel approach to interaction with digital devices in everyday life. This approach is based on a human-centered design, utilizing wearables like head-mounted displays to free individuals from limitations such as the need to use their hands for input or to look away and focus directly on a screen. Nevertheless, the design of head-mounted displays relies heavily on vision, which poses significant challenges for certain disabled users, specifically blind people. Then, this paper discusses the concept of accessible heads-up computing for blind people. It argues that by combining the state of the art in heads-up computing with the application of accessibility guidelines, it is possible to achieve accessible heads-up computing. The paper also introduces the reader to visual impairment and the relationship between head-mounted displays (HMDs) and blindness, discussing the concept of heads-up computing concerning blind people. Finally, we present an example of accessible heads-up computing: an HMD-based VR escape game, applying and adapting game accessibility guidelines for the blind.

Keywords: Head-Up Computing · Head Mounted Display · Virtual Reality · Accessibility · Visual Impairment · Blindness.

1 Introduction

Billions of people around the world have some visual impairment [1]. As a result, they have to adapt to living with their disability and even use technological devices. However, new technologies can sometimes exclude people with disabilities. This can be the case for blind people who use head-mounted displays (HMDs), devices commonly explored by heads-up computing. Heads-up computing proposes a new way of interacting with digital devices in everyday life, using HMDs as a core technology [31]. This concept is not far from reality, as the new models of HMDs could become a standard. However, the design of HMDs relies heavily on vision, which poses significant challenges for blind users, such as interacting with the environment, moving around, interacting with others, and more [22,49,50,51]. There is currently no data on the number of HMD users who are blind. However, this does not mean that blind people are not interested or eager to use these devices [52].

On the other hand, there have also been some advances in accessibility in HMD-based virtual reality. For example, Zhao *et al.* worked on a haptic cane controller to provide access to a virtual environment for people with visual impairments [8]. Some researchers have designed accessible environments with auditory and haptic representations of objects [22,21]. In addition, others have used virtual environments to train the navigational skills of blind people [19,20].

Despite these advances in accessible heads-up computing, some designers continue to develop limited applications for "standard" (sighted) users. Several factors may contribute to this, including a lack of developer training in accessibility [47], the additional cost and time required to develop accessible features [53], and the fact that these contributions require extra equipment or are only used in research contexts [49]. Then, accessible heads-up computing must still be achieved by including blind people in its design.

This work proposes applying game accessibility guidelines in VR applications to achieve accessible heads-up computing and presents an ongoing game as an example. Then, the paper provides insights into visual impairment, exploring the concept of the world and the challenges blind people face. This is followed by a section on the relationship between HMDs and blindness, and a discussion about the features HMDs provide that can be further exploited. Later, the paper focuses on the concept of accessible heads-up computing and how it could be achieved through accessibility guidelines. The following section shows an HMD-based VR game for blindness as an example of an escape room VR application that used game accessibility guidelines and co-design with a blind user. Finally, there is a discussion and conclusion section about this work in progress.

2 Visual Impairment

Worldwide, at least 2.2 billion people experience either near or distant visual impairment due to various causes such as refractive errors, cataracts, glaucoma, congenital conditions, age-related degeneration, and more [1]. In addition, visual impairment, also known as vision impairment, is a term that encompasses various types and degrees of vision loss. Some researchers categorize them based on the degree of loss, such as "not impaired", "low vision", and "blind" [2,3].

In overcoming the challenges of visual impairment, these individuals often need to adjust and adapt to living with their disability. This adaptation includes treatment and rehabilitation, such as training with Orientation & Mobility (O&M) instructors "to develop or regain the ability to move independently and safely through the environment" [5]. In addition, visually impaired people (VIPs) must adapt and integrate digital technologies into their daily lives. For example, blind users rely on keyboard navigation when using their computers because it works better with screen reader programs [4]. Another example is their ability to use non-visual text input to communicate on mobile devices. According to Azenkot and Lee, non-sighted people use the voice input feature more often and send longer messages than sighted people [6].

However, accessibility to digital technologies is not always dependent on VIPs, as VIPs can also be excluded by designs that do not provide adequate features or accommodations. These technologies often reflect a bias towards a "standard" body [7] stereotype in their design. Therefore, new technologies must be designed with accessibility and inclusion in mind so that no one is excluded.

3 Head Mounted Display And Blindness

According to Shibata, a head-mounted display (HMD) is an "image display unit mounted on the head" that renders stereoscopic images through two separate lenses [10]. These stereoscopic images change according to the user's head motion (position and rotation) [10] and allow the user to perceive depth and have a sense of spatial location [12]. To track head movements, the HMD has some tracking sensors, gyroscopes, and accelerometers [11]. However, the HMD is designed to display stereoscopic images and has stereo speakers to reproduce spatial audio.

A Head-Related Transfer Function (HRTF) makes the spatial audio effect possible, which describes how a sound reaches a listener's ear [15]. This function considers several variables such as the point of source, the shape of the head, the shape of the ear, the frequencies, and more [15,14]. As a result, a person can locate the source of a sound.

In addition, the head-mounted displays have a binaural rendering system with head tracking, which updates the HRTFs and sound directions according to head movements [16]. As a result, users can perceive sounds more naturally and feel more immersive. Therefore, head-mounted displays are not only visual displays but can also be used for auditory displays. Previous researchers have used the visual and aural capabilities of HMDs for research involving people with low vision or blindness [17,19,20,21,22,24].

HMDs also have haptic and speech-processing capabilities. More specifically, they provide haptic feedback through input devices or controllers. Most HMDs track these controllers using a camera-based tracking method combined with computer vision called SLAM (Simultaneous Localization and Mapping) [25,26]. However, both controllers must be within the field of view of the cameras or sensors to operate. Conversely, the HMDs also have a built-in microphone for social interaction or communication. However, this microphone can also be used for speech-processing functions. For example, the Apple Vision Pro has a voice control feature that introduces a new way to navigate using voice commands [27]. Then, it is a fact that head-mounted displays have evolved from simple image displays to almost wearable computers.

According to Li *et al.*, head-mounted displays can be used specifically as assistive and therapeutic devices for visually impaired people, with augmented reality (AR) used for assistive purposes and virtual reality (VR) used for therapeutic applications [17]. The functionality also depends on the type of HMD. HMDs can be classified as Immersive Extended Reality (IXR), Optical See-Through (OST), and Retinal Projection (RP) [17,18]. The IXR HMDs are devices that cover the user's entire field of view and can display virtual reality and (in some cases) augmented reality environments. The last IXR device models have external cameras that transmit images of the environment into the display lenses [29,28] and use them to display virtual objects in Augmented Reality. On the other hand, OST HMDs use a semi-transparent mirror [17] to display images or holograms in front of the user. Most of these devices look like glasses and are widely used in augmented reality. Finally, the RP HMDs are devices that "directly project a see-through image onto the user's retina" [18], and they are less commonly used [17].

Nevertheless, it is impractical for people with blindness to use OST or RP devices. These types of HMDs, which rely on augmented reality, have adequate functionality when assisting low-vision individuals, but they are not yet suitable for assisting blind individuals [17]. Instead, IXR devices are better suited for therapeutic applications with blind people. For assistive purposes, there are very few cases where IXR devices are employed. However, these limited cases are focused on integrating computer vision with mixed reality [24,32].

IXR devices have been employed for the specific purpose of teaching navigation skills, learning echolocation, training daily activities, investigating accessibility, and even assisting in forming cognitive maps[3] [20,21,22,24,23]. Moreover, head-mounted displays are not only utilized for training purposes. Additionally, they facilitate novel forms of interaction with others through virtual reality or "Metaverse" platforms, such as VRChat, Roblox, and Meta Horizon Worlds, where millions of users engage and interact on a daily basis [30]. Consequently, accessibility to these platforms and devices is of paramount importance, as the majority of them continue to rely heavily on visuals, thereby excluding blind individuals. It is imperative that visually impaired individuals have the opportunity to benefit from head-mounted displays beyond the realm of training.

4 Accessibility in Heads-Up Computing

Heads-up computing proposes a new way of interacting with digital devices in everyday life. It is based on a human-centered approach through wearables, freeing individuals from limitations such as needing to use their hands for input or looking away and focusing directly on a screen [31]. This new concept presented in 2023 clearly reflects the evolution of computers (wearables) to a human-centered interaction with these devices. According to Zhao *et al.*, users can use heads-up computing glasses in combination with a voice assistant to "search for ingredients in the refrigerator using augmented labels" and then "cook the ingredients while adjusting the playback of a guided video", all in a hands-free manner. This scenario is not far from reality with advances in head-mounted display models such as the Apple Vision Pro and the Meta Quest 3 [13,28]. These two devices demonstrate impressive mixed reality capabilities.

[3] A cognitive map is a mental representation of a physical place. It is used to navigate and move through the physical world correctly.

To continue, Heads-Up Computing presents the concept of hands-free interaction with human-centered devices. This hands-free interaction is done through a camera-based hand-tracking method, providing a better experience and a more natural way to interact with objects [34]. However, hands-free interaction also reduces performance compared to traditional controllers, as users may feel less control, precision, and dominance [35]. In addition, removing the controllers can reduce accessibility for blind people by excluding another sensory input and output: the tactile sense. Button presses (input) and haptic feedback (output) provide another complement to compensate for the lack of vision. Then, when the controllers are removed, blind users are left with only their sense of speech and hearing. This is the case with the Apple Vision Pro, which does not provide controllers with the head-mounted display [28]. Instead, users should look for external devices to connect to the HMD, such as a supported game controller. Heads-up computing also offers options besides controllers, such as a ring mouse with a cursor, vibration output, and gesture recognition [31]. However, blind people are not accustomed to cursors, relying instead on keyboard navigation [4]. Therefore, there is still room to improve accessibility in Heads-Up Computing. For example, some researchers have proposed using a haptic and auditory cane controller for blind people to navigate in virtual reality [38].

Head-mounted displays also continue to develop new ways to navigate; for example, the Meta Quest Pro and the Apple Vision Pro offer eye tracking as another input feature [36,28]. However, this navigation relies on vision, which may exclude blind people if it becomes an industry standard. On the other hand, Apple has compensated for this vision feature by adding a screen reader called VoiceOver and a navigation feature called Voice Control. Indeed, VoiceOver "gives audible descriptions of what's in view" and allows interaction by using VoiceOver gestures with one or both hands [33]. This VoiceOver feature was a great addition to the head-mounted display, but it still needs evaluation to see if it achieves its goal. Conversely, the Voice Control feature provides an accessible way to interact with the interface [27]. This voice control is also presented in Meta head-mounted displays and works with specific commands, such as "Shutdown, Restart, Open Library, Play, Pause, Open Messages, Who's Online, etc.".[37].

In addition, accessibility is not entirely determined by the hardware, such as head-mounted displays, controllers, or wearables; it also depends on enhancing software with accessible features for blind people. Therefore, the applications inside the head-mounted displays must follow some accessibility principles or guidelines to achieve accessibility. There are several accessibility guidelines in the literature, such as Web Content Accessibility Guidelines [39], Game Accessibility Guidelines [40], Accessibility Guidelines for VR Games [42], Accessibility Design Documentation for VR [43], and more. Designers can follow this documentation to adapt VR applications to the needs of a wide range of users through universal design [7].

The accessibility guidelines for blind people can be divided into four groups: Sound and Audio Feedback, User Configuration, User Experience, and Design Process [44,45]. Within the sound and audio feedback group, the guidelines emphasize using unambiguous auditory feedback to alert users to changes [40]. It also shows the importance of allowing objects to broadcast their presence in the environment [44]. The second group (User Configuration) will enable users to configure the software according to their needs. For example, they can adjust the speed of the environment, customize controllers, or configure volume settings [45]. To continue the third group (user experience) improves the interaction and engagement of the user within the software. These guidelines suggest presetting some features recommended for specific user groups (e.g., blind users) [9] and including tutorials or an orientation phase [43]. Finally, the last group (design process) suggests some guidelines to follow during the design phase of the software. For example, designers should involve users through participatory design [45], and they should also integrate feedback through haptics [43].

In summary, it is essential to develop universal hardware and software that does not exclude any group of users. This applies not only to the blind but also to people with hearing or motor impairments. People cannot be excluded from Heads-Up Computing.

5 An HMD-Based VR Game For Blindness

The game is designed to serve as an exemplar of accessible heads-up computing, with a particular focus on the needs of blind individuals. Consequently, it is not intended for exclusive use by blind individuals; sighted individuals can also play it.

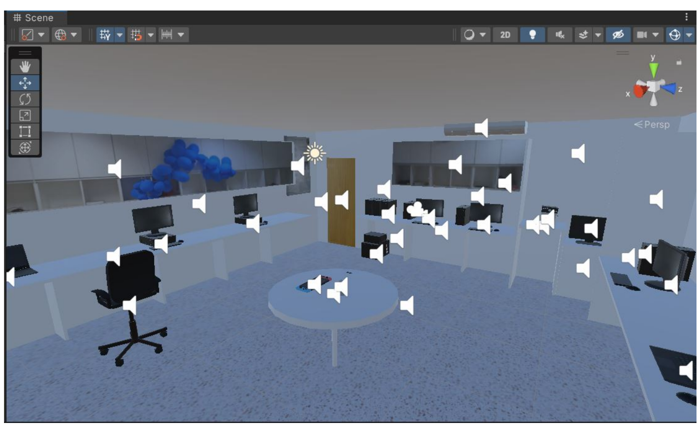

Fig. 1. Designing the prototype in Unity.

The selected game genre is the escape room, in which a player or group of players "discover clues, solve puzzles, and perform tasks in one or more rooms to achieve a specific goal (usually escape from the room)" [46]. This game genre was chosen because of the challenge of making it accessible, as it relies on the player's attention to visual details to progress and solve the puzzles. Several escape room games involve point-and-click actions, requiring players to move the mouse and click on specific objects. Some examples include the "The Room" game series[4], the "Rusty Lake" game series[5], and the "Escape Simulator" series[6]. Therefore, this game genre requires a lot of attention to visual feedback. Furthermore, few studies have investigated accessibility in virtual reality escape rooms. One is "Access to Escape," which teaches designers about accessibility guidelines in a VR escape room. However, this game was not tested with visually impaired people, and the authors also mentioned that the game could not yet "meet the requirements of an accessible VR game" [47]. The other game is "Loud and Clear", which presents the premise of an escape game with no visuals. The researchers wanted to "illustrate the challenges of being blind in a playful setting" [48]. They received positive feedback from sighted people, but they did not test the game with VIP to assess the level of accessibility [48]. Then, there seems to be a research opportunity to explore accessibility in VR escape room games.

Currently, this work is being developed using Unity[7]. This software is a game engine that provides a suitable environment for virtual reality development. Also, this work uses the Meta Quest 2, which can be classified as an Immersive Extended Reality (IXR) HMD [17,18].

To achieve accessibility, this work consulted accessibility guidelines from the literature [43,40,9,44,41,45], selected a set of relevant guidelines, and adapted them to meet the needs of an accessible escape room game. It is important to note that this work is still in progress (Fig 1). Therefore, the application or adaptation of the guidelines is still ongoing. Specifically, these are the changes that have been made:

- Addition of a training environment for practicing the mechanics of the game.
- Including footstep cues when moving and turning.
- Implementation of directional cues when turning, so that blind players know which direction they are facing.
- Configuration of XR controllers to limit the range of the ray interactor to 0.1 meters and restrict its functionality to the right controller.
- Rearrangement of movement with the controllers, now the player only moves with the left thumbstick and rotates with the right.
- Addition of unique auditory name descriptions for objects.
- Implementation of collision cues when running into objects.
- Introduction of auditory sounds for use as spatial landmarks, such as the sound of an air conditioner or birds.
- Incorporation of a configuration menu for volume reduction/enhancement of audio sound effects, audio descriptions, music, etc.

These changes were inspired by guidelines such as "Guidance by Sound References", "Distinct Audio for Game Feedback", "Object Presence", "Adjustment

[4] https://www.fireproofgames.com/games/the-room
[5] https://www.rustylake.com/
[6] https://pinestudio.com/games/escape-simulator
[7] https://unity.com/

of Volume Settings", "Guidance Phase or Tutorial", "Information as Needed", and "Text to Speech" [43,40,9,44,41,45]. Some changes were also made through a collaborative design with a blind person[8]. This person tested an earlier version of the game and expressed that it was difficult to locate in the environment while rotating with the body and moving with the thumbstick. In this case, movement with the joysticks alone should predominate. Another recommendation was to use "unique auditory name descriptions" because having multiple objects with the same name made it confusing to distinguish between them, whether the user was looking at the same object or not. Also, when the game's mechanics were explained, the individual had problems applying them. A "tutorial" was then implemented. Finally, the user mentioned that using a "heavy device" on the head felt strange, but this comment could not be improved. An alternative would be to limit the duration of the game to a certain time or to allow the user to save the game and continue at another time.

6 Conclusion

Accessible heads-up computing can be achieved by designing accessible hardware and software. HMDs offer a comprehensive set of accessibility features, including haptics, speech processing, head tracking, processing power, and stereo speakers. However, developers still need to learn how to apply accessibility guidelines to achieve good software accessibility. In addition, researchers' contributions need to begin to move beyond the prototype context and be used in industry.

This work shows an example of accessible heads-up computing using an Immersive Extended Reality HMD [17,18], an escape room game, and various game accessibility guidelines. It is a work in progress that can be improved with more guidelines and feedback from blind people. For future work, this game will be evaluated by more blind users and HCI (Human-Computer Interaction) experts.

Nevertheless, we believe there seems to be an opportunity to explore accessibility in VR escape room games and other VR applications. Some future changes include the application of more guidelines such as "Diverse Input" [43,40,9,44,41,45], which suggests also accepting voice commands as diverse input. In fact, voice commands could increase the level of accessibility of the game.

In conclusion, this work proposes that combining heads-up computing and game accessibility guidelines represents a promising approach to developing accessible heads-up computing for blind individuals.

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References

1. WHO: Blindness and vision impairment, https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment, last accessed 2024/04/08
2. Lewis, A., Norwich, B.: Special teaching for special children? Pedagogies for inclusion: a pedagogy for inclusion? McGraw-Hill Education (UK) (2004)
3. Pascolini, D., Mariotti, S. P.: Global estimates of visual impairment: 2010. British Journal of Ophthalmology 96(5), 614–618 (2012).
4. Raufi, B., Ferati, M., Zenuni, X., Ajdari, J., Ismaili, F.: Methods and Techniques of Adaptive Web Accessibility for the Blind and Visually Impaired. In: Procedia - Social and Behavioral Sciences, vol. 195, pp. 1999-2007 (2015).
5. Jacobson, W. H.: The art and science of teaching orientation and mobility to persons with visual impairments. American Foundation for the Blind (1993).
6. Azenkot, S., Lee, N. B.: Exploring the use of speech input by blind people on mobile devices. In: Proceedings of the 15th International ACM SIGACCESS, pp. 1–8 (2013).
7. Clarkson, P. J., Coleman, R., Keates, S., Lebbon, C.: Inclusive design: Design for the whole population (2013).
8. Zhao, Y., et al. Enabling people with visual impairments to navigate virtual reality with a haptic and auditory cane simulation. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, pp. 1–14 (2018).
9. Leite, P. D. S., Almeida, L. D. A.: Extended analysis procedure for inclusive game elements: Accessibility features in The Last of Us Part 2. In: International Conference on Human-Computer Interaction, pp. 166–185. Springer (2021).
10. Shibata, T.: Head mounted display. Displays 23(1–2), 57–64 (2002). ISSN 0141-9382. https://doi.org/10.1016/S0141-9382(02)00010-0.
11. Renganayagalu, S.K., Mallam, S.C., Nazir, S.: Effectiveness of VR Head Mounted Displays in Professional Training: A Systematic Review. Tech Know Learn 26, 999–1041 (2021).
12. Jones, G. R., Lee, D., Holliman, N. S., Ezra, D.: Controlling perceived depth in stereoscopic images. In: Stereoscopic Displays and Virtual Reality Systems VIII, vol. 4297, pp. 42-53. SPIE (2001).
13. Meta Quest 3: Specifications, https://www.meta.com/quest/quest-3/, last accessed 2024/04/11
14. Broderick, J., Duggan, J., Redfern, S.: "The Importance of Spatial Audio in Modern Games and Virtual Environments," in *2018 IEEE Games, Entertainment, Media Conference (GEM)*, Galway, Ireland, 2018, pp. 1-9.
15. Li, S., Peissig, J.: Measurement of Head-Related Transfer Functions: A Review. *Applied Sciences*, vol. 10, no. 14, 5014 (2020).
16. Hong, J. Y., He, J., Lam, B., Gupta, R., Gan, W.-S.: Spatial Audio for Soundscape Design: Recording and Reproduction. *Applied Sciences*, vol. 7, no. 6, 627 (2017).
17. Li, Y., et al. A Scoping Review of Assistance and Therapy with Head-Mounted Displays for People Who Are Visually Impaired. *ACM Transactions on Accessible Computing*, 15(3), Article 25. (2022)
18. Ehrlich, J. R., Ojeda, L. V., Wicker, D., Day, S., Howson, A., Lakshminarayanan, V., Moroi, S. E.: Head-mounted display technology for low-vision rehabilitation and vision enhancement. *American Journal of Ophthalmology*, 176, 26-32 (2017).
19. Thevin, L., Briant, C., Brock, A. M.: X-road: Virtual reality glasses for orientation and mobility training of people with visual impairments. *ACM Transactions on Accessible Computing (TACCESS)*, vol. 13, no. 2, pp. 1–47 (2020).

20. Allain, K. et al.: "An audio game for training navigation skills of blind children," in *2015 IEEE 2nd VR Workshop on Sonic Interactions for Virtual Environments (SIVE)*, Arles, France, 2015, pp. 1-4.
21. Moldoveanu, A. Dragos Bogdan et al.: "Virtual environments for training visually impaired for a sensory substitution device," in *2017 Zooming Innovation in Consumer Electronics International Conference (ZINC)*, Serbia, pp. 26-29 (2017).
22. Guerreiro, J., et al.: "The Design Space of the Auditory Representation of Objects and Their Behaviours in Virtual Reality for Blind People," in *IEEE Transactions on Visualization and Computer Graphics*, vol. 29, no. 5, pp. 2763-2773 (2023).
23. Dove, G., et al.: Digital Technologies in Orientation and Mobility Instruction for People Who are Blind or Have Low Vision. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2), 1-25 (2022).
24. May, K. R., et al.: Spotlights and Soundscapes: On the Design of Mixed Reality Auditory Environments for Persons with Visual Impairment. *ACM Transactions on Accessible Computing*, vol. 13, no. 2, Article 8, 47 pages (2020).
25. Hattori, K., Hirai, T.: Inside-out tracking controller for VR/AR HMD using image recognition with smartphones. In: *ACM SIGGRAPH 2020 Posters*, pp. 1-2 (2020).
26. Grimm, P., Broll, W., Herold, R., Hummel, J., Kruse, R.: VR/AR Input Devices and Tracking. In: Doerner, R., Broll, W., Grimm, P., Jung, B. (eds) *Virtual and Augmented Reality (VR/AR)*, Springer, Cham, 2022.
27. Apple: Apple Vision Pro User Guide, https://support.apple.com/guide/apple-vision-pro/voice-control-tan14d179ad1/visionos, last accessed 2024/04/22
28. Apple: Apple Vision Pro, https://www.apple.com/apple-vision-pro/, last accessed 2024/04/19
29. Meta: Meta Quest Pro Tech Specs, https://www.meta.com/quest/quest-pro/tech-specs/#tech-specs, last accessed 2024/04/19
30. Han, J., Liu, G., Gao, Y.: Learners in the Metaverse: A systematic review on the use of Roblox in learning. *Education Sciences*, 13(3), 296 (2023).
31. Zhao, S., Tan, F., Fennedy, K.: Heads-Up Computing Moving Beyond the Device-Centered Paradigm. *Communications of the ACM*, 66(9), 56-63 (2023).
32. Lumen: Glasses that empower the blind, https://www.dotlumen.com/, last accessed 2024/04/23
33. Apple: Apple Vision Pro User Guide, https://support.apple.com/guide/apple-vision-pro/turn-on-and-practice-voiceover-tanae5174040/visionos, last accessed 2024/04/22
34. Masurovsky, A., et al. Controller-free hand tracking for grab-and-place tasks in immersive virtual reality: Design elements and their empirical study. *Multimodal Technologies and Interaction*, 4(4), 91 (2020).
35. Voigt-Antons, J. N., et al. Influence of hand tracking as a way of interaction in virtual reality on user experience. In: *2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX)*, pp. 1-4, IEEE (2020).
36. Meta: Eye Tracking, https://www.meta.com/pt-br/help/quest/articles/getting-started/getting-started-with-quest-pro/eye-tracking/, last accessed 2024/04/23
37. Meta: What you can say with Voice Commands on Meta Quest, https://www.meta.com/help/quest/articles/in-vr-experiences/oculus-features/what-you-can-say-with-voice-commands/, last accessed 2024/04/23
38. Zhao, Y., et al. Enabling people with visual impairments to navigate virtual reality with a haptic and auditory cane simulation. In: *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pp. 1-14 (2018).

39. W3C: WCAG 2 Overview, https://www.w3.org/WAI/standards-guidelines/wcag/, last accessed 2024/04/24
40. International Game Developers Association: Game Accessibility Guidelines, https://gameaccessibilityguidelines.com/, last accessed 2024/04/24.
41. Microsoft: Xbox Accessibility Guidelines, https://learn.microsoft.com/en-us/gaming/accessibility/guidelines, last accessed 2024/04/24.
42. Heilemann, F., Zimmermann, G., & Münster, P.: Accessibility guidelines for VR games - A comparison and synthesis of a comprehensive set. *Frontiers in Virtual Reality*, 2, 697504 (2021).
43. Meta: Designing Accessible VR, https://gameaccessibilityguidelines.com/, last accessed 2024/04/24.
44. Façanha, A. R., Darin, T., Viana, W., Sánchez, J.: O&M indoor virtual environments for people who are blind: A systematic literature review. *ACM Transactions on Accessible Computing (TACCESS)*, 13(2), 1-42 (2020).
45. Coronado, A., Carvalho, S., Berretta, L.: Game accessibility: Adaptation of a digital escape room game to improve spatial cognitive skills in blind people. In: *Proceedings of the 25th Symposium on Virtual and Augmented Reality*, pp. 174-182 (2023).
46. Fotaris, P., Mastoras, T.: Escape rooms for learning: A systematic review. In: *Proceedings of the European Conference on Games Based Learning*, pp. 235-243 (2019).
47. Mateen, S., Wiesemüller, P., Voß-Nakkour, S.: Access to Escape: Didactic Conception and Accessible Game Design of a VR-Escape Room for Accessibility Education.
48. Baas, B., et al. Loud and clear: the VR game without visuals. In: *Games and Learning Alliance: 8th International Conference, GALA 2019, Athens, Greece, November 27–29, 2019, Proceedings 8*, pp. 180-190. Springer International Publishing.
49. Ribeiro, R. A., et al.: Investigating Virtual Reality Locomotion Techniques with Blind People. In: Proceedings of the CHI Conference on Human Factors in Computing Systems, pp. 1-17. Association for Computing Machinery, USA (2024).
50. Ji, T. F., et al.: VRBubble: Enhancing Peripheral Awareness of Avatars for People with Visual Impairments in Social Virtual Reality. In: Proceedings of the ACM SIGACCESS Conference on Computers and Accessibility, pp. 1-17. (2022).
51. Mendes, J. M. A.: Sonic Arrow: Investigating Aiming in Virtual Reality with Blind People. Doctoral dissertation. (2024).
52. Andrade, R., Rogerson, M. J., Waycott, J., Baker, S., Vetere, F.: Playing Blind: Revealing the World of Gamers with Visual Impairment. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pp. 1-14. (2019).
53. Aguado-Delgado, J., Gutierrez-Martinez, J. M., Hilera, J. R., de-Marcos, L., & Otón, S.: Accessibility in video games: A systematic review. Universal Access in the Information Society, 19, 169-193. (2020).