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19 February 2026
Total Citations: 0
Total Downloads: 673

Published: 26 October 2025

[Citation in BibTeX format](#)

ASSETS '25: The 27th International ACM
SIGACCESS Conference on Computers
and Accessibility
October 26 - 29, 2025
Colorado, Denver, USA

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POSTER

An Initial Exploration of Low-Cost VR for People With Mobility Disability

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Abstract

VR has become a pivotal technology for entertainment, education, and social interaction. With this, much research examined how the accessibility of VR systems can be improved to facilitate participation among diverse user groups. However, most research has focused on high-end systems that require a considerable financial investment. In contrast, low-cost VR setups have received less attention in research, and the accessibility of those systems remains underexplored. Through an exploratory interview study with six participants with diverse mobility disabilities, we examine the accessibility of low-cost VR setups and their interaction methods. Our initial findings reveal several accessibility issues with low-cost VR, as well as barriers that are also present in high-cost VR, along with opportunities to enhance the accessibility of VR systems. We present three overarching themes that reflect the accessibility of state-of-the-art, low-cost VR setups and provide a future direction for accessibility research in this field.

CCS Concepts

• **Human-centered computing** → **Accessibility design and evaluation methods.**

Keywords

Accessibility, Cardboard VR, Smartphone VR, Virtual Reality

ACM Reference Format:

Anna Steffens, Dmitry Alexandrovsky, Kathrin Gerling, and Marvin Wolf. 2025. An Initial Exploration of Low-Cost VR for People With Mobility Disability. In *The 27th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '25)*, October 26–29, 2025, Denver, CO, USA. ACM, New York, NY, USA, 5 pages. <https://doi.org/10.1145/3663547.3762152>

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ASSETS '25, Denver, CO, USA

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ACM ISBN 979-8-4007-0676-9/25/10

<https://doi.org/10.1145/3663547.3762152>

1 Introduction and Background

Virtual Reality (VR) has applications in work, education, or leisure [20], but access barriers for people with disabilities remain [17, 24]. In the case of physical disability and mobility disability, this not only includes barriers related to interactions within virtual worlds but also challenges associated with the setup of devices. For instance, Mott et al.'s seven accessibility barriers explicitly include putting on and taking off the VR Head-Mounted Displays (HMDs) or wielding motion controllers [24]. Similarly, Creed et al. described barriers related to software and hardware usability, ethics, collaboration, and interaction as the output of multidisciplinary sandpits with people with physical disabilities and industry specialists [9]. Physical access to VR was also investigated through the lens of wheelchair users, as exemplified by Gerling and Spiel [18], who proposed design implications for engaging with VR design, or with a focus on upper body impairments and their interplay with locomotion methods (cf. Franz et al. [14]). These individual findings often complement each other, and efforts have been made to formulate universally applicable design principles. For example, Dudley et al. [12] posed output and input redundancy, integration of assistive technology, customizability, enhanced assistance, and inclusive design as high-level principles for accessible VR. Several attempts have been made to improve VR accessibility through dedicated designs that offer alternatives to common interaction techniques, e.g., by addressing the often forced bimaneuality of VR [35] or extending established scene-viewing methods [13].

Beyond physical and digital accessibility, a recurring concern is associated with the high cost of VR systems [9, 16]. Here, low-cost alternatives to the high-end VR systems may offer a promising alternative to lower financial barriers to VR [10, 29]. In particular, smartphone VR systems leverage a technological platform already available to many people - smartphones - and combine them with low-cost headsets and dedicated controllers (see Figure 2). Here, low-budget alternatives to high-end VR systems, such as cardboard VR, can serve as a valuable approach for equitable VR in classrooms [7, 22] to facilitate digital inclusion [29]. Although Google discontinued the Cardboard VR in 2021 [11], developers, public institutions, and researchers still use these low-cost devices [7] and

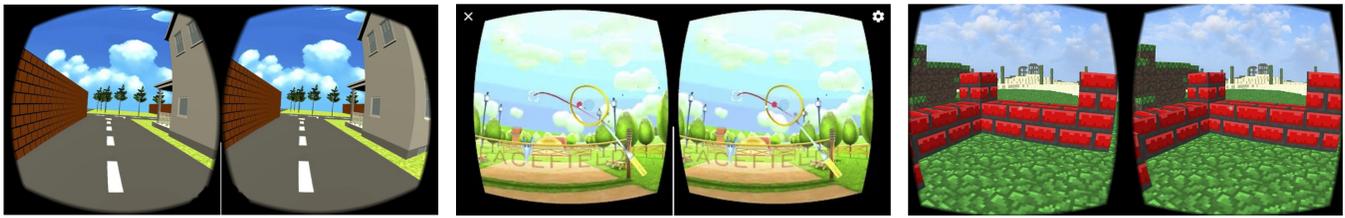


Figure 1: Applications included in our study: VR Maze [15] (left), BadmintonVR [25] (middle), Mineforge VR [21] (right).

continue the development of DIY and low-cost VR systems (cf. Silveira et al. [29], Tong et al. [31]). However, research has primarily examined low-cost VR from a financial barriers perspective, and little is known about its accessibility characteristics for people with mobility disability, or to what extent access barriers associated with high-end VR systems also apply to low-cost VR.

We address this gap through an initial exploration of the accessibility of low-cost VR for people with mobility disability through an interview study and hands-on exploration of exemplary VR systems that involved six persons with mobility disability, investigating the research question (RQ): **To what extent are low-cost VR systems accessible and comfortable to use for people with mobility disability, and which features enhance or hinder accessibility?**

Through Thematic Analysis [4], we show that many of the accessibility concerns present in high-end VR also apply to and are exacerbated in the context of low-cost VR, preventing people with mobility disability from obtaining the same benefits as non-disabled peers. Most importantly, there is a need for accessible input methods that align with prominent research directions in high-end VR and must be extended to the design of accessible hardware suited for one-handed input, which is common in low-cost VR.

Our work paves the road for follow-up research exploring low-cost pathways toward accessible VR, and we close with an overview of avenues for future work.

2 Interview Study: Exploring the Accessibility of Low-Cost VR With People With Mobility Disability

Here, we give an overview of the qualitative research process. We first describe the method, the participants, and the procedure. Then we comment on the analysis and our positionality before presenting the results.

2.1 Method

Semi-structured interviews. The interview guide was designed to explore how participants experienced low-cost VR, identifying positive aspects as well as areas where participants experienced barriers. The interviews aligned with previous work exploring high-end VR [23] and covered the setup, experience, and exit phases, with subcategories including comfort, usability, interaction, and navigation. For example, questions such as *"How did you experience the preparation of the systems?"* helped to explore participants' initial challenges and the ease of adapting to the VR environment. Other questions, such as *"Do you use any strategies to operate the*

VR headsets or controllers?" and *"Would you want to change anything to improve the VR experience for people with disability?"*, were aimed at uncovering specific interaction techniques and potential improvements for accessibility. The full guide is in the supplementary materials.

Hands-on exploration of low-cost VR. The interviews included an exploration phase where participants could try out low-cost VR systems. This included different controller variants with a plastic and cardboard head-mounted display (HMD; see Figure 2) as well as three distinct smartphone VR applications (see Figure 1): (1) VR Maze [15] is a puzzle where the player's goal is to navigate through a labyrinth while collecting items. The game is controlled via head movement and was included to represent a VR environment that heavily emphasizes navigation. (2) BadmintonVR [25] is a sports game in which players engage in badminton, integrating head movement to manipulate the virtual racket and hit the shuttlecock. The game was chosen as an example of a hands-free input variant. (3) Mineforge VR [21] is a sandbox game akin to Minecraft [26], which can be controlled via gaze or controller input, combining button and joystick input. We included the application because it was slow-paced and heavily relied on controller input.

2.2 Participants and Procedure

We recruited six participants (four women, two men, no non-binary persons) aged 22 to 66 for our study. Participants had different types of physical disability. For five participants, their disability impacted their fine motor skills. Five participants were occasional or regular wheelchair users, with one participant alternating between a powered wheelchair and a walker. One participant used an electric leg prosthesis. All but one participant had prior experience using VR, and two participants owned a high-end VR headset (Meta Quest 3).

At the beginning of the study, participants consented to take part and were informed about the research. Then, they were asked for demographic information. Afterwards, they could explore the different VR applications with other setups. Next, they took part in an interview designed to explore their experiences. On average, sessions lasted for about an hour, and the participants were reimbursed with 10€. All sessions were audio recorded. The research protocol was approved by the ethics committee of the Karlsruhe Institute of Technology under an umbrella agreement.

2.3 Data Analysis and Positionality

A member of the research team first transcribed data and then analyzed by the same person using Thematic Analysis [4]. Initial



Figure 2: (a): Cardboard VR [19]: A cardboard casing for the HMD with the smartphone device. The smartphone is positioned with the display facing the user’s eyes, rendering a stereo image of the scene. To enter VR, the user puts on the goggles and looks through the display a separate image for each eye. (b): Shinecon VR headset [28]: Plastic HMD casing for a smartphone. The headset has a head strap to secure the device on the head and additional headphones that can be connected to the smartphone. (c): VR Case [6]: A ca. 10 cm long handheld with a joystick and six buttons on the top. In the front, the controller has two trigger buttons. (d): Mini Gamepad [3]: The game pad has a size of 7.45 x 3.4 x 1.75 cm and is intended to be held in two hands. The gamepad has a joystick on the left and four buttons arranged in a rectangle to the right. (e): Mini Remote Ring [1]: The Ring is a small-scale (7.1 x 7.1 x 4.1 cm) controller worn on a finger. It has a joystick and four buttons on the top surface. To the front are two additional buttons sitting below each other.

codes were systematically generated to capture key insights on accessibility and comfort within each phase of VR engagement. These codes were grouped into themes, which were reviewed within the research team and refined to ensure they aligned with the data and the research question. Through this process, we identified three key themes related to the barriers and opportunities presented by low-cost VR systems for users with disabilities.

Given the reflexive nature of our analysis, we briefly reflect on our positionality. Our research team comprises individuals with backgrounds in Computer Science, Rehabilitation Engineering, Cognitive Science, and Game Design. No member of the research team has a physical disability. We have extensive experience in designing accessible immersive systems and firmly believe that everyone should be able to experience them.

2.4 Results

In this section, we discuss the three themes that we crafted from our data.

2.4.1 Theme 1: Not All Low-Cost VR Systems are Equal in Terms of Accessibility and Comfort. Considering the initial setup of the HMD, participants noted that the insertion of the smartphone into the Shinecon VR headset poses difficulties: *"It's quite a fiddly job to get it in there. I would need someone to do it for me every time."* (P2). Likewise, adjusting the head straps was an accessibility barrier, mirroring findings for high-end VR systems [24]. Here, the cardboard headset offered an alternative that does not require fastening; however, having to hold the HMD in place throughout interaction introduced additional issues for wheelchair users who needed to use their hands for wheelchair navigation: *"But of course it's a bit annoying when you have to hold on to your glasses at the top. Yes, so it's rather unpleasant that you still have to hold on to it. Then the hands I use to move around are in use somewhere else."* (P3).

Regarding the controllers, feedback was mixed. Two participants who experienced numbness in their fingers attempted to use all three controllers, but faced difficulties in holding them and feeling or pressing the buttons, which are much smaller than those used for high-end VR systems. *"It feels like you have to control it with a winter glove. You can feel that something is there, but where is my thumb on this device [controller] or where are my fingers, I can't tell [gamepad]."* (P2). This was echoed by P6: *"The buttons are far too flat. I can't feel them at all. I have to look closely every time."* In contrast, P5 noted: *"I was so critical at first, but the little one [gamepad] is actually the best for my little hands because the buttons are all in the front and I don't have to think so much in my head. Everything is close together; you don't have to reach far."* Two other participants reported experiencing finger pain after using the controllers, e.g., *"My muscles get tired quickly and then something that requires a lot of fine motor skills like this [controller] isn't so good. My hands already hurt a bit."* (P4). In terms of facilitators of access, P3 specifically highlighted that the Mini Remote Ring was beneficial: *"Regarding the controller, I think I would really like to be able to hold it firmly in my hand and control the wheelchair properly at the same time. And that was the case with the Mini Remote Ring controller,"* highlighting its potential for wheelchair users. Likewise, participants with disabilities that impacted their fine motor skills appreciated this controller *"Because the fact that I can put this through my finger means that it can't rotate in my hand."* (P6).

2.4.2 Theme 2: A Low-Fidelity VR System Only Provides a Basic Experience of Presence. Despite the low fidelity, some participants reported enjoying engaging with low-cost VR, for example, stating that *"It took a little while to get used to [the movement], but then I actually found it quite enjoyable."* (P4 playing VR Maze game using Cardboard VR). In contrast, those participants who had previously used high-end VR were less enthusiastic, explaining that *"I didn't feel like I was here in this room. I'm just in this other [virtual] room."*

But the graphics... I don't know. It's simply worse than this one [Meta Quest 3]. Not sure if I like it.(P5). Interestingly, the quote suggests that the participant experienced presence (i.e., the sense of being in the virtual world [2, 27]) despite the low quality, indicating that low-cost VR still delivers on the basic promises of the technology. At the same time, being fully immersed in VR was a concern for participants, with one person commenting that *"So if I had been outside this test environment, I would of course have taken my [VR] glasses off again and again."* (P2), highlighting that boundary guardian systems included in high-end VR (cf. Wu et al. [34]) are essential for a safe experience. However, we also note that two participants experienced mild simulator sickness, with one participant pointing out that *"It's a bit uncomfortable when it's running for you and you're not moving."* (P5 playing VRMaze game using Cardboard VR), suggesting that partial automation of user movement induced nausea. Here, we note that simulator sickness has also been reported for high-end VR (cf. Van Gemert and Bergstrom [32], Wang et al. [33]), but it should be explored whether the lower degree of user control in low-end VR increases the risk of simulator sickness.

2.4.3 Theme 3: The Choice and Combination of Interaction Paradigms Impacts Accessibility. The reliance of low-cost VR on head movement increased its accessibility for some participants, appreciating the intuitiveness of the approach, *"It's easier, somehow more intuitive. I can't really feel the buttons, and I'm always looking for them, which is frustrating, and the [gaze-based interactions] work surprisingly well."* (P6). At the same time, other participants commented that the head movements were challenging: *"My rotation in my head is also a bit limited. I can go further to the left than to the right. And of course, that's a bit of a restriction for the game."* (P3 playing BadmintonVR game using Cardboard VR). The joint use of multiple interaction paradigms was perceived as overwhelming: *"Because I was concentrating on the room [in the virtual world] and I had something else in my hand, so there was something extra. And then I also had to think, now I don't just have to move with my head. I also have the controller in my hand, which is added to the mix."* (P4).

In terms of interaction paradigms, some participants highlighted that voice control might be an accessible alternative: *"What was it like again? [...] You could somehow just tell it [Meta Quest 3] what to open and then it did it. I think that's also kind of an intuitive method."* (P5). Likewise, hand tracking was seen as a promising opportunity, with one participant explaining that while pressing buttons was difficult, bringing together fingers for gestures was feasible for them.

3 Discussion and Future Work

While our work is only a preliminary exploration of the accessibility of low-cost VR for people with mobility disability, mirroring other exploratory studies at ASSETS [8, 17], and follow-up research with larger participant samples is needed, it has successfully uncovered an initial set of access barriers and facilitators. These findings advance existing research on equitable immersive technology (cf. Silveira et al. [29]) by providing essential details related to the accessible design of VR devices. In response to our RQ, we conclude that low-cost VR is accessible on a basic level, but that adaptations need to be made to the headset and certain controller types for interactions to be comfortable.

Our work shows that the distinct features of low-cost VR simultaneously act as both accessibility barriers and facilitators. Here, we discuss our core findings in the context of accessibility concerns related to high-end VR.

Focus Point 1: HMD Design. Our results show that the HMD design interacts with accessibility during setup and interaction (see Section 2.4.1). Strap adjustment was difficult to handle during the setup phase, mirroring findings on high-end VR that likewise identified adjusting the HMD as a key barrier [18, 24]. However, while the strapless cardboard VR variant facilitated more straightforward setup and headset removal, the need to hold the headset during interaction introduced a new access barrier. Here, future work should explore alternative headset designs, such as methods for adjusting straps that are also accessible via a single-handed setup, particularly for individuals with limited fine motor control.

Focus Point 2: Controller Shape and Button Size. Low-cost VR offers a broader range of controller designs than high-end VR (see Figure2). Our work shows that known issues regarding button size and placement persist (cf. Dudley et al. [12], Mott et al. [23]), but that alternative controller shapes can act as facilitators of access (see Section 2.4.2), e.g., in the case of the Mini Remote Ring that was perceived as beneficial as it could be held more easily. This presents an opportunity for future work to more broadly explore VR controller layouts that reduce the need to hold and stabilize controllers during interaction, directly attaching them to users' bodies or assistive devices, similar to the work on chairables [5].

Focus Point 3: Interaction Paradigms. Many of the applications available in the context of low-cost VR combine interaction paradigms, which can be overwhelming for users (see Section 2.4.3). Our work shows that the heavy reliance on head-based interaction paradigms (e.g., head movement or gaze input that can also trigger head movement during engagement) can be problematic for people with mobility disability, further supporting previous anecdotal findings on high-end VR [16]. Here, we note that underlying conditions of mobility disability (e.g., a spinal cord injury) can also impact head movement [30], which should therefore be designed with care when addressing disabled users.

Acknowledgments

We thank all participants for contributing their time to our research. Funded/Co-funded by the European Union (ERC, AccessVR, 101115807). Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council. Neither the European Union nor the granting authority can be held responsible for them.

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