Comparing Interaction Methods in a VR Rock Climbing Simulation

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Abstract

In this research paper, we present an empirical analysis of interaction methods in virtual reality (VR) simulations of extreme sports, with a specific focus on a rock-climbing simulation developed in Unity. Leveraging the Meta Quest controllers, hand tracking technologies, and TactGloves by bHaptics, this study aims to identify the most effective VR interaction modality that enhances user engagement, realism, and safety in simulated extreme sports environments. Through a comparative analysis of these interaction methods, the research investigates the potential of VR technologies to deliver immersive and realistic extreme sports experiences without the associated risks. The study employs a mixed-methods approach, combining quantitative performance metrics with qualitative user feedback to evaluate the efficacy of each interaction method in terms of immersion, usability, and user satisfaction. Preliminary results indicate that, contrary to initial expectations, hand tracking technologies provided users with a heightened sense of immersion compared to the advanced haptic gloves. This unexpected outcome, emerging from challenges encountered during the integration of bHaptics software, suggests that hand tracking might offer more promising avenues for training, rehabilitation, and entertainment in the realm of extreme sports VR simulations, and that more research is needed in field of haptic gloves. This paper contributes to the growing body of literature on VR interaction methods by providing insights into the benefits and limitations of various technologies, thereby informing future developments in VR simulations for extreme sports and beyond.

Keywords: VR Interaction, Extreme sport simulation, Virtual Reality Hand tracking, VR gloves, Haptic feedback

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1 Introduction

Virtual Reality (VR) has ushered in a new era of digital interaction, enabling users to experience immersive environments with unprecedented realism. Specifically, in the context of climbing—one of the extreme sports—VR offers a safe yet exhilarating platform to mimic the intricate movements and psychological aspects associated with the sport. This research focuses on the climbing experience within VR, employing a simulation developed in Unity [1] to investigate how different interaction methods affect user engagement and performance.

In our climbing simulation, players can interact using VR controllers, hand tracking, and TactGloves by bHaptics [2]. Each method offers a distinct mode of interaction: VR controllers provide a standard, familiar interface; hand tracking offers intuitive, natural movements; and TactGloves deliver tactile feedback, simulating the texture and resistance one would feel when gripping real climbing holds.

Our primary aim is to determine which interaction method most effectively enhances the climbing experience in VR. We posit that a more immersive and interactive method can significantly improve the user's skill acquisition, strategy planning, and overall enjoyment. This is particularly relevant in a sport like climbing, where tactile feedback and precise movements are crucial.

The value of VR in simulating risk-laden sports like climbing extends beyond entertainment. It provides a platform for athletes to train, experiment with strategies, and refine their skills without the physical dangers associated with the sport. This aspect has been highlighted in previous studies, such as those by Döllinger et al. [3] and Sawade [4], who emphasize VR's potential to transform training and performance in extreme sports.

The haptic feedback provided by TactGloves is of particular interest due to its ability to replicate the tactile sensations of climbing, which are essential for a realistic and beneficial training experience. Studies by Lee et al. [5] and Patel et al. [6] support the notion that haptic feedback can significantly enhance spatial awareness and user interaction in VR, an idea further reinforced by the Haptic Fidelity Framework proposed by Muender et al. [7].

This research is structured to meticulously evaluate the different interaction methods within VR climbing simulations. After an in-depth review of VR technologies and their application in simulating extreme sports, we will analyze the specific contributions of VR controllers, hand tracking, and haptic feedback gloves. A comparative analysis, supported by a user study with our rock climbing simulation, will follow. We will conclude with discussions on our findings and their implications for future VR applications in extreme sports training and simulation.

2 Literature review

VR technologies, through their evolution, have sought to bridge the gap between virtual experiences and real-world sensations, a pursuit that has seen the development of various interaction methods aimed at enhancing user engagement and realism. This section delves into the related work surrounding extreme sports VR simulations, focusing on the interaction methods employed, their inherent advantages and drawbacks, and briefly compares these with the our approach.

2.1 Extreme Sports VR Simulations Projects

The application of VR in simulating extreme sports has grown in popularity, driven by the desire to safely replicate the thrill and challenge of sports like rock climbing within a virtual setting. Projects like the rowing simulation developed by Shoib et al. [8] and the robotic disaster response simulation by Agüero-Durán et al. [9] exemplify the diverse applications of VR in creating complex, interactive environments. Steindl's exploration of hybrid tracking technology [10] targets the accuracy and realism needed for virtual rock climbing simulations. The VreeClimber project, which combines a movable climbing wall with VR, offers a notable example of how VR can enhance the realism and safety of climbing simulations, by integrating hand tracking to maintain a realistic representation of the climber's movements [11]. This approach aligns with the principle that VR can significantly enhance skill acquisition and performance in complex tasks, as evidenced by Seymour et al. [12], directly applicable to extreme sports VR simulations. Pagé et al. utilized VR to improve decision-making skills in basketball, showcasing VR's potential in enhancing cognitive aspects of sports, which are crucial in navigating the challenging terrains in rock climbing [13].

2.2 Hardware Technologies in Use

In VR simulations, the hardware technologies range from traditional controllers to hand tracking and haptic gloves, each offering different levels of interaction fidelity. Controllers provide precision but may not replicate the naturalistic feel of climbing. Hand tracking technologies offer an intuitive interface, enabling users to maneuver in the virtual space in a more lifelike manner. However, they can sometimes be inaccurate and do not provide tactile feedback. Haptic gloves, particularly the bHaptics TactGloves [14], represent a significant leap forward by delivering detailed tactile responses, mirroring the textures and resistances encountered in actual rock climbing.

2.3 Drawbacks and Advantages

Each interaction method comes with its set of advantages and drawbacks. Traditional controllers are lauded for their reliability and precision but fall short in immersive quality. Hand tracking offers a more natural interaction experience but can suffer from inaccuracies and lacks tactile feedback [6]. Haptic gloves bridge these gaps by delivering precise tactile feedback, although they are not without challenges, including high production costs and integration complexities [6, 14]. The tactile feedback technology, particularly as implemented through devices like the TactGloves, provides a compelling solution to these issues by offering a more immersive and intuitive interaction method that closely mimics real-world sensations.

2.4 Comparison with Our Method

Our study employs the bHaptics TactGloves within a VR rock climbing simulation, diverging from previous studies that predominantly used controllers or hand tracking. Our approach capitalizes on the haptic gloves' advanced feedback mechanisms to enhance the climbing experience, offering a tactile dimension that closely resembles the real-world activity. This research aims to discern how tactile feedback influences user interaction and realism in VR, contrasting the experiences provided by TactGloves with those from other hardware technologies.

3 Case study

This section delves into the specifics of how our VR climbing simulation was constructed, detailing the creation of an immersive environment, the choice of location for the simulation, and how various elements were integrated to provide a realistic climbing experience.

3.1 Application design and structure

In our study, we developed an immersive VR environment based on Babin Zub, a towering, slender, and spiky rock formation that emerges into view after exiting an old Austrian tunnel near Sarajevo. Utilizing Unity, we employed a 360-degree camera image to construct a realistic skybox. Additional elements like foliage and grass were sourced from the Unity Asset Store [15], while rocks were custom modeled in Blender to enhance realism (see Figure 1).

Figure 1: The Babin Zub VR environment in Unity.

Figure 2: Climbable ball meshes.

Figure 3: Hovering over climbable mesh using VR Controllers.

To accurately model the rock surface, Blender [16] was utilized to sculpt the virtual representation of Babin Zub. The integration of the XR Interaction Toolkit enabled locomotion and interaction through various user actions. Climbable objects (see Figure 2), marked as meshes, were

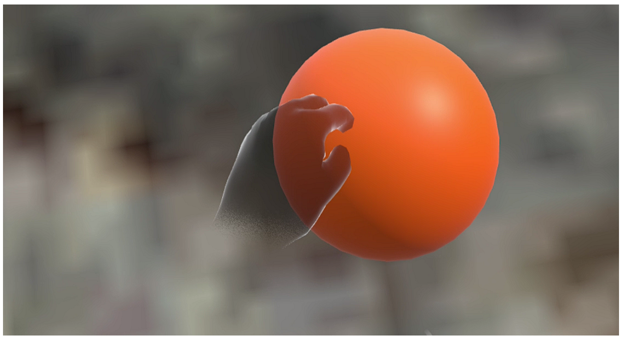

Figure 4: Grabbing the climbable mesh using Hand Tracking.

strategically placed to designate interactive points on the rock, guiding users through their virtual climbing experience.

The interaction with these points is visually represented by color changes in the climbable ball meshes: white indicates an inactive state with no user interaction, blue appears when a user hovers over the climbable object, signaling readiness for interaction, and orange denotes that the user is actively engaging with the object, either by pressing and holding the trigger button or by using hand tracking to grasp the object (see Figures 3 and 4).

The bHaptics SDK is a pivotal component of the application, enabling haptic feedback inside the Unity editor. This SDK allows the application to communicate with bHaptics TactGloves, sending precise feedback based on users hand location within the virtual environment.

3.2 Implementation

The implementation phase involved integrating various components to enable a comprehensive VR climbing experience. The XR Toolkit facilitated the creation of an XR Rig, providing foundational support for locomotion methods such as continuous movement, teleportation, and, crucially, climbing. Hand tracking capabilities were introduced, allowing users to interact with the environment not only through VR controllers but also via natural hand movements, enhancing the immersive quality of the simulation (see Figure 5). Following the integration of these interaction functionalities, our attention turned to the environment's design. We implemented a procedural terrain system. This system allowed us to automate the placement of foliage, enabling us to distribute various trees and plants across the terrain seamlessly. By utilizing this procedural approach, we gained the flexibility to easily manipulate the ecosystem's composition, adjusting the density and variety of the vegetation to achieve the desired level of realism and environmental complexity (see Figure 6). After the addition of climbable objects, we advanced to the integration of haptic feedback in the VR environment. We imported the SDK from bHaptics and utilized their scripts to establish a connection between the climbable objects and the

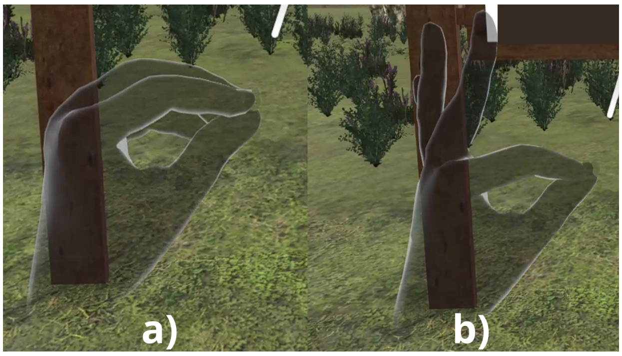

Figure 5: Grab activation using a)Hand Tracking and b)TactGloves.

VR controllers/hand tracking system. This was achieved by adding specific tags to the climbable meshes, which, when interacted with by the controllers or hands, would trigger haptic feedback, simulating the sensation of touching or gripping the objects.

Figure 6: Showcase of the realistic skybox and background.

Our next step focused on refining the user experience by implementing a heads-up display (HUD). This HUD plays a crucial role in guiding the player through the climbing experience, providing real-time feedback on their progress toward the goal or indicating if they have failed to complete a specific challenge. Recognizing the limitations of hand tracking technology, particularly the inability of cameras to detect hands covered by gloves, an experimental approach was taken to adapt the TactGloves. We developed custom scripts intending to enable the gloves to function akin to VR controllers, with simplified hand motions designated for 'grab' and 'move' functions. However, these adaptations faced challenges, as the responsiveness of the scripts did not meet the project's requirements. One of the most challenging aspects of the implementation was the integration of bHaptics TactGloves. The lack of readily available tutorials necessitated a deep dive into older documentation to locate the SDK for bHaptic products. The primary goal was to achieve haptic feedback upon interaction with climbable objects, simulating the tactile sensation of touching or gripping the rock surface. However, initial attempts to provide direct feedback to the specific hand engaging with an object encountered technical hurdles. Ultimately, a compromise was reached where both gloves would activate upon interaction, offering a uniform haptic response that, while not individually targeted, significantly enhanced the overall sense of touch within the simulation. Additionally, the experiment explored the handling of gravity within the VR environment. A glitch was identified wherein the physics engine did not consistently calculate falling gravity across interaction methods, leading to the disabling of fall mechanics during certain builds. Notably, the gravity fall feature functioned only when using the VR controller's joystick. This inadvertent design consequence had a silver lining: beginner VR users experienced a less discouraging introduction to VR climbing, as the absence of fall consequences reduced frustration and the likelihood of early cessation of the activity.

3.3 Interaction in application

The simulation's interaction design leverages various input methods, including VR controllers, hand tracking, and haptic gloves, to create a comprehensive and engaging user interface. The use of VR controllers is a standard mode of interaction, allowing users to navigate the virtual environment and interact with objects through familiar button presses and joystick movements. Specific actions, such as grabbing or initiating movement, are assigned to designated buttons (see Figure 7). The trigger button, for instance, is used to simulate the act of grasping climbable points on the rock, while the left joystick facilitates movement within the virtual space. The right joystick enables snap turn, and the B button (secondary button) is used for the restart function.

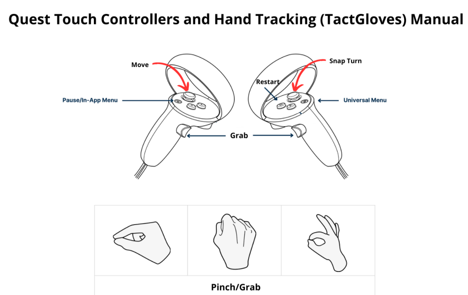

Figure 7: Manual for movement.

Hand tracking introduces a more naturalistic layer of interaction, enabling users to engage with the environment using their hand movements and gestures. This method allows for intuitive actions like pinching or reaching out to simulate grabbing and climbing without the need for physical controllers. Specifically, the pinch gesture is employed as the primary interaction mechanism for 'grabbing' in the virtual environment. This choice is underpinned by the gesture's distinct visibility to the headset's cameras. The pinch motion, characterized by bringing the thumb and a finger together, creates a clear and recognizable signal for the hand tracking system. The hand tracking system translates these real-world gestures into corresponding virtual actions, enhancing the immersion and realism of the climbing experience.

The integration of bHaptics TactGloves provides tactile feedback that corresponds to the user's virtual activities. The gloves are designed to deliver vibrating sensations that mimic the tactile experience of touching or gripping the rock surface. When a user interacts with a climbable mesh, the gloves activate, delivering feedback that enhances the perception of contact and grip. This haptic response is crucial for creating a convincing and immersive climbing experience, as it bridges the gap between visual input and physical sensation.

4 User experience evaluation

The simulation tasked participants with ascending a virtual model of Babin Zub, engaging with climbable objects via each interaction method. To ensure a systematic analysis, participants were instructed to utilize the interaction methods in a specific sequence: initially with VR controllers, subsequently through hand tracking, and finally employing hand tracking with the TactGloves. This sequence was intended to standardize the experiment's procedure and minimize any potential learning effects. Notably, the climbing task was not time-constrained, allowing participants to proceed at their own pace, thereby facilitating a more authentic assessment of each method's immersive quality and user-friendliness.

4.1 User study description

A total of 29 participants engaged in a sequential trial of the three interaction methods within a VR rock climbing simulation (see Figure 8). They started first with VR controllers, hand tracking and then hand tracking using TactGloves. The average testing lasted around 10 minutes per person. Following the interaction, participants completed a questionnaire assessing various aspects of their experience, including immersion, realism, ease of use, and physical comfort.

The user study was conducted in the VR laboratory at SSST[17], designed to ensure consistent conditions for all participants. The environment was equipped with a standard VR setup, including a high-performance computing system and a designated play area with adequate space for movement. Lighting and acoustics were optimized to minimize external distractions, ensuring that participants' experiences were solely influenced by the VR simulation. At the outset of the testing session, participants were thoroughly briefed on the rules and procedures. They were informed that they would be participating individually, which allowed for a focused and undisturbed experience. Additionally, they were assured of their autonomy during the experiment, with the explicit option to terminate their participation at any point should they experience discomfort, dizziness, or any other adverse effects, thereby prioritizing their safety and well-being.

Figure 8: The testing process for each user from using VR Controllers, Hand Tracking to TactGloves.

4.2 Results

Regarding immersion, participants' feedback highlighted a clear preference for hand tracking as the most immersive interaction method, with 48.7% of participants favoring it, compared to 35.1% for VR controllers and 16.2% for haptic gloves (see Figure 9). Despite the technological improvement of haptic gloves, their current implementation was less immersive for the majority of users, potentially due to the existing challenges in their integration and responsiveness.

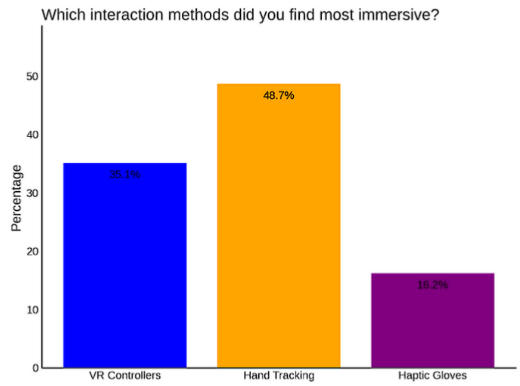

Figure 9: Distribution of participant preferences for immersive interaction methods.

The evaluation of interaction methods revealed distinct user preferences and experiences. While VR controllers were considered the most immersive by nearly half of the participants, the ease of use was notably higher for hand tracking, with 56% of participants finding it very easy to

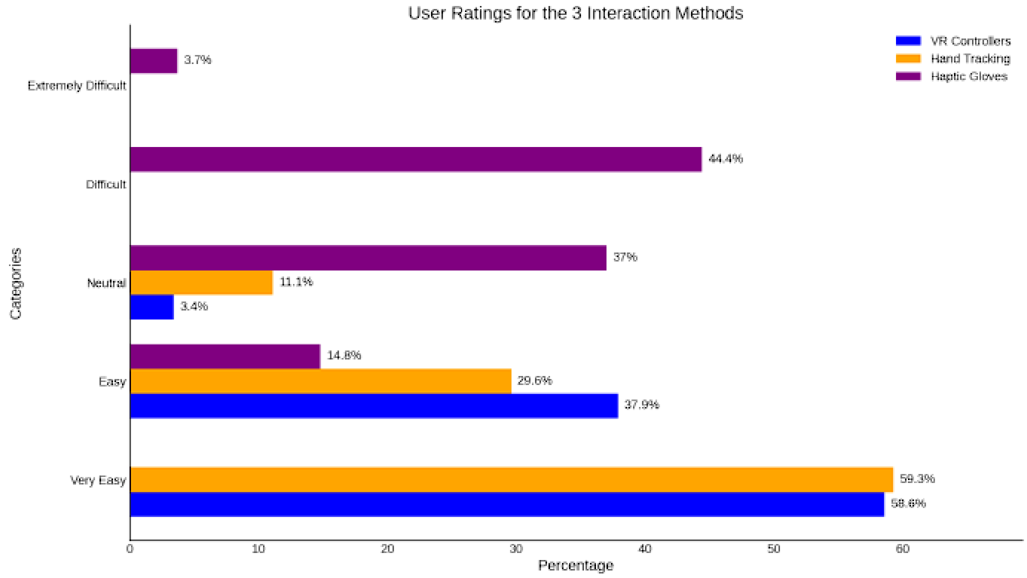

Figure 10: Rated ease of use for all three interaction methods using the Likert Scale.

use. In contrast, haptic gloves, despite their potential for enhanced tactile feedback, were rated as difficult by 48% of the participants (see Figure 10).

Haptic feedback, a core aspect of our study, showed promising yet mixed results. The majority of participants acknowledged the realism of haptic feedback when using controllers (66.7%) and gloves (64%). However, the feedback from gloves did not universally translate to a more immersive or preferred experience, highlighting the complexity of integrating tactile sensations in a manner that consistently enhances user experience (see Figure 11).

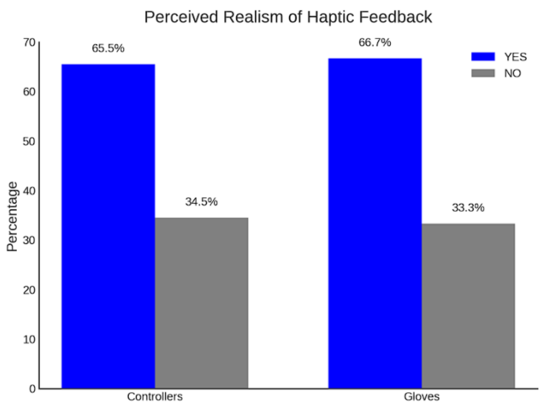

Figure 11: Graphic illustration of participant responses on the realism of haptic feedback using VR controllers and TactGloves.

Looking ahead, the majority of participants (90%) expressed interest in using haptic gloves for other simulations, suggesting a strong perceived potential for this technology, provided that issues related to responsiveness and tracking accuracy are addressed. This enthusiasm aligns with our focus on refining the gravity mechanics and developing more precise TactGlove implementations in future iterations of the simulation. By improving these aspects, we aim to enhance the realism and user engagement, potentially making haptic gloves a preferred method for interaction in VR simulations beyond rock climbing. Participants appreciated the overall experience, suggesting minor adjustments for enhanced realism and interaction quality. There were mentions of the potential for competitive elements and a desire for further development of the haptic gloves.

5 Conclusion and future work

The research conducted provided valuable insights into user experiences with different VR interaction methods in a rock climbing simulation. Through a comprehensive study the investigation shed light on the comparative effectiveness, realism, and user preferences associated with VR controllers, hand tracking, and bHaptics TactGloves. The findings indicated a general preference for hand tracking in terms of immersion and realism, though the haptic gloves offered unique tactile feedback that some users found more realistic and engaging.

Despite the innovative approach, the study unveiled challenges, particularly with the TactGloves and gravity mechanics within the simulation. The attempt to integrate the gloves as functional controllers highlighted the current technological limitations, affecting user experience and interaction precision. Furthermore, inconsistencies in gravity simulation revealed areas where the VR environment's realism could be enhanced. As for the future work we will concentrate on refining the gravity mechanics within the VR simulation to enhance realism and consistency. This improvement is essential for a more immersive and authentic rock climbing experience. Additionally, the development will focus on improving the precision and responsiveness of the TactGloves. The aim is to achieve a more intuitive interaction, where users do not need to consciously adjust their hand positioning for the gloves to function effectively. Enhancing gesture recognition and sensor technology will be key to this advancement.

These enhancements, verified through further user testing, will not only elevate the user experience in the rock climbing simulation but could also inform interaction designs in other VR applications, expanding the impact of this research in the field of virtual reality.

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