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Master's Thesis
Academic Year 2025

Blind Soccer Virtual Reality Training

Keio University
Graduate School of Media Design

Fu Zening

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Fu Zening

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Abstract of Master's Thesis of Academic Year 2025

Blind Soccer Virtual Reality Training

Category: Design

Summary

This thesis presents "Blind Soccer Virtual Reality (VR) training", a non-visual VR training system designed to support beginners, both sighted and visually impaired, in learning the fundamental skills of blind soccer. Built using Unity and compatible with Meta Quest and bHaptics wearable devices, the system creates an entirely dark virtual environment where players navigate and interact solely through spatial audio and foot-based haptic feedback. The project aims to design a non-visual blind soccer VR experience that uses audio and vibration to provide an alternative option for people who want to experience Blind Soccer but do not have the specialized ball, the team or coach. Iteratively developed across four stages, including doing the field work to understand the sport, design the system, test and optimize the system, and evaluation. By combining technological experimentation with human-centered design, Blind Soccer VR Training contributes to the field of inclusive VR design and provides an alternative option for people to experience blind soccer in immersive environments.

Keywords:

Human and Computer Interaction, Inclusive Sport, Virtual Reality, Visually Impaired, Audio Guidance, Haptic Feedback

Keio University Graduate School of Media Design

Fu Zening

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Chapter 1
Introduction

1.1. What is inclusive sports

In contemporary discussions at the intersection of sports science and social integration, the terms adaptive sports [1] and inclusive sports [2] are often used interchangeably. However, they differ fundamentally in both philosophical orientation and implementation. Adaptive sports are designed to allow people with disabilities to participate in athletic activities through targeted modifications to the equipment and environment. This approach emphasizes the individual's adaptation to the activity, for example, the use of carbon fiber prosthetics for amputees in running or customized wheelchairs in basketball. Although adaptive sports represent significant technological progress, they often exist within parallel structures, such as the Paralympics, that reinforce separation rather than integration [3].

In contrast, inclusive sports aim to integrate people with diverse abilities, disabled and non-disabled, within a shared sporting environment [3]. Rather than tailoring individuals to fit the activity, inclusive sports focus on adapting the activity to accommodate all participants. This may involve redesigned rules, assistive devices, or cooperative game-play structures that promote mutual support and equal access. The objective extends beyond functional compensation, striving for social inclusion, shared agency, and equitable participation. Accessibility, in this context, is not treated as an auxiliary requirement but is embedded as a fundamental design principle [4].

The concept of inclusive sports can be traced back to the mid-20th century, a period marked by growing criticism of the traditional sports model that prioritized uniform physical ability while excluding individuals with disabilities. In the aftermath of World War II, the increasing need for rehabilitation and social reintegration among injured veterans led to the emergence of *rehabilitative* *sports and adaptive sports* in Europe and North America. These practices offered personalized athletic opportunities for people with visual, auditory, or mobility impairments, such as the blind, the deaf, and amputees [5]. However, these early approaches were largely based on a segregated structure, where athletes with disabilities participated in separate training systems and competitions under modified rules, thus reinforcing, rather than dismantling, the boundaries between ability groups.

From the late twentieth century to the early twenty first century, the growing awareness of disability rights and the spread of *inclusive education* prompted a critical reassessment of the role of sports in promoting social integration [6]. In this context, the concept of *inclusive sports* gradually emerged. Its core principle is integration rather than segregation: Within a shared sporting environment, participants of all physical, sensory, and cognitive abilities should be treated equitably and actively supported [7]. Through adaptations to rules, collaborative structures, and assistive technologies, inclusive sports enable diverse individuals to participate in the same athletic activity together. The goal extends beyond mere participation; It aims to foster equality, mutual respect, and a sense of belonging [7].

Today, inclusive sports have been endorsed by major international bodies such as the United Nations and the International Paralympic Committee (IPC), and are increasingly integrated into national education systems, community initiatives, and public policy frameworks [8] [9]. Representative examples include mixed-ability basketball, blind soccer, inclusive relay races, and tandem cycling events that involve wheelchair users and able-bodied participants. As the field continues to evolve, it is also intersecting with emerging digital technologies, including virtual and augmented reality (VR&AR), wearable devices, and Human-Computer Interaction (HCI) research, pushing the boundaries of inclusive sports beyond physical space into virtual and mixed reality environments.

An paradigmatic case is blind soccer. Blind soccer is often misclassified as an adaptive sport that is only for visually impaired people; in fact, blind soccer is an inclusive sport. Outfield players can be individuals with visually impaired people with different types and different levels, and full vision people, but all outfield players are required to wear an eye mask during the game to make sure the match is fair. While goalkeepers and guild people should have full vision and do not need to wear eye masks. Guild people provide information and guidance to guide outfield players with sounds. [10]

Blind soccer embodies the concept of inclusive sport. Inclusion here is not achieved by restoring or compensating for sight, nor by restricting participants to the visually impaired, but by enabling both visually impaired and sighted people to participate together through appropriate rule modifications. In this way, inclusive sport not only expands access to sport, but also promotes the integration of impaired and healthy people, weakens boundaries between groups, and promotes equality, respect, and a sense of social belonging among different groups.

1.2. What is Blind Soccer

Blind soccer, also known as 5-a-side football, originated in the mid-20th century in South America, particularly within schools for the visually impaired in countries such as Brazil and Argentina. In its earliest form, the sport was informal and unstandardized, spontaneously organized by blind students as a recreational activity. These games not only provided enjoyment, but also helped players develop auditory localization and motor coordination skills in the absence of visual input. As participation increased, efforts to formalize the sport emerged in the late 1970s. Countries such as Spain and Brazil began to establish preliminary rules and organize national championships, laying the foundation for a structured blind football competition.

Since the 1980s, blind soccer has gradually expanded in Europe, Asia, and Latin America, accompanied by the growing formalization of its competitive structure. In 1996, the International Blind Sports Federation (IBSA) officially incorporated blind soccer into its governance framework and began standardizing competition rules worldwide [10]. This marked a key turning point in the sport's transition to internationalization.

Blind soccer made its official debut at the 2004 Paralympic Games in Athens and has since become a regular fixture at every Summer Paralympic Games. Beyond its increasing athletic sophistication, the sport has gained recognition for its educational, rehabilitative, and social inclusion potential. Many countries have established national teams and youth development programs, while also promoting blind soccer at the grassroots level through schools and community initiatives.

The size of the game field is the same as FIFA field (40 meters $\times$ 20 meters) with boards to stop the ball from going out. Each match is 30 minutes and divided into 15 minutes halves.

Each team consists of five players: four outfield players and one goalkeeper. Outfielders are mostly people with various types of visual impairments, but even with visual impairments because of the type and degree of impairment, some people are not completely blind [11], therefore, to ensure fairness, all outfielders are required to wear blindfolds. When the outfield players are moving, they need to say "Voy, Voy" loudly to let other outfield players know where they are, to avoid collision and to decide where to move to. Goalkeepers, who are of full vision or partial vision with B2 or B3 level and do not wear eye masks, are the only visual players allowed on the field. In addition, each team has a guide outside the field behind the opposing team's goal. The guide is sighted, and the guide provides information to outfielders who are attacking through verbal commands to help attacking players determine the direction and distance to the goal of the opposing team. [10]

The ball contains bells inside, which make sound during movement. Players use auditory perception, spatial memory, and proprioceptive feedback to locate, catch, and kick the ball. Fouls, penalties, and tactical elements are governed by a modified version of FIFA's futsal rules, adapted to account for the non-visual modality of play. Furthermore, blind soccer incorporates additional safety and procedural regulations specific to its non-visual format. For example, any call made during the game must be clearly communicated to the recording desk, verbally, or through an established signal system. In the event that the referee identifies an issue with the player's equipment, such as a loose or improperly secured eye mask, the player must leave the field to address the problem unless it has already been resolved on the spot. A player who has exited the field for such reasons is not permitted to reenter without explicit permission from the referee. Equipment that poses a safety risk, such as a damaged or unstable eye mask, may be disallowed at the discretion of the referee to ensure the safety of all participants.

The sport emphasizes not only technical ability, physical fitness, and spatial awareness, but also mutual trust through verbal communication between teammates. The mixed configuration of sighted and non-sighted people promotes an inclusive form of collaboration in which different sensory abilities are collectively utilized. Far from being a game exclusive to blind athletes, blind soccer is an example of inclusive sport design that demonstrates how equity can be achieved not by restoring impaired sensory abilities or limiting the participating population to the impaired, but by redesigning the game model.

1.3. Rise of Virtual Reality

Virtual reality (VR) refers to a computer-generated, immersive three-dimensional interactive environment that allows users to engage with and manipulate digital content through multiple sensory channels, including vision, hearing, and touch. Rather than merely presenting images or animations, VR offers a spatial and embodied experience that emphasizes both a sense of presence, feeling physically situated within the virtual environment, and a sense of agency, the ability to intentionally act and influence that environment from a first-person perspective.

A typical VR system consists of three core components: sensory input devices, a computational engine for scene generation and processing, and output display mechanisms. Users interact with the system through head-mounted displays (HMDs), motion controllers, hand and body tracking sensors, and, in more advanced setups, eye trackers and electromyography (EMG) sensors. These devices capture the user's position, orientation, gestures, and physical movements, which are then processed in real time by the system. The VR engine responds by rendering dynamic visuals, spatialized audio, and, where applicable, force feedback or haptic sensations at high frame rates and low latency. This feedback loop enables a closed multimodal interaction cycle that reinforces the user's sense of immersion and embodied presence within the virtual environment.

The development of VR can be traced back to the 1960s. In 1968, computer graphics pioneer Ivan Sutherland and his student created the first head-mounted three-dimensional display system, known as the "Sword of Damocles", which is widely considered the prototype of modern VR [12]. During the 1970s, organizations such as NASA and the US Air Force began to experiment with image-based flight simulation systems for training in high-risk operational scenarios. Throughout the 1980s and 1990s, VR emerged as a prominent concept in popular science and technology culture. However, because of limitations in hardware performance and production cost, its application remained largely confined to research laboratories and demonstration environments.

In the 21st century, especially in the early 2010s, with breakthroughs in graphics processors (GPUs), inertial measurement units (IMUs), OLED displays, spatial positioning algorithms, and wireless transmission technologies, VR has entered the stage of practicalization and consumerization [13]. The launch of the Oculus Rift in 2012 marked a turning point, sparking renewed interest in immersive technologies. This was soon followed by devices like HTC Vive and PlayStation VR, which expanded VR applications to gaming, film, design, education, and healthcare [14]. More recently, the development of standalone headsets such as the Meta Quest series, Valve Index, and Apple Vision Pro has further lowered entry barriers and broadened the reach of VR systems. Alongside this hardware evolution, open source tools and user-driven platforms like VRChat and Rec Room have fostered an increasingly diverse and participatory content ecosystem.

Today, VR is evolving beyond a niche entertainment medium into a multidisciplinary, embodied computing platform. Its applications span HCI, cognitive and neural sciences, architectural visualization, social communication, and therapeutic rehabilitation [15]. By allowing users not only to observe, but also to construct and inhabit digitally mediated spaces, VR redefines traditional notions of spatiality, presence, and agency. The miniaturization of hardware, the decrease in costs, and the increasing availability of content have contributed to its growing integration into daily life. More importantly, VR offers novel frameworks for inclusivity: creating environments where physical restrictions can be bypassed, perceptual modes can be reimagined, and new forms of social participation can emerge.

In terms of application, VR technologies have been widely adopted in diverse domains such as entertainment, education, medicine, industry, and architecture. In gaming, VR offers a level of spatial immersion and physical interactivity far beyond traditional screens, integrating visual, auditory, and haptic feedback into a unified experience. In the medical field, VR has been used for surgical training, pain management, and psychological treatments such as exposure therapy for Post-Traumatic Stress Disorder (PTSD) and acrophobia. In educational and museum settings, it allows immersive historical reconstructions and experiential learning. Meanwhile, in industrial design and architecture, VR facilitates three-dimensional prototyping, visualization, and remote collaborative evaluation.

From a sociocultural perspective, the impact of VR extends beyond its role as a technological tool, increasingly shaping new forms of perception, embodiment, and identity [15]. It offers alternative experiences that transcend physical limitations, for example, allowing individuals with paraplegia to walk in virtual environments or allowing elderly users to stroll through digital parks from their homes. In addition, VR provides a novel platform for multisensory interaction, remote socialization, and identity exploration, where users can engage in game, gatherings, collaboration, and even psychological therapy through their avatars in shared virtual spaces.

However, the widespread adoption of VR has also introduced a range of challenges, including motion sickness, cybersickness, potential cognitive and postural effects from prolonged use, concerns over privacy and data security, and the risk of social isolation [16]. These issues have sparked ongoing debates in both the academic and ethical domains.

In summary,VR is not merely a technological tool, but a medium that is actively reshaping how humans perceive the world and interact socially [17]. Its core value lies not in replicating reality, but in constructing new possibilities, creating equitable, accessible experiential spaces for individuals of diverse abilities, identities, and backgrounds. This potential positions VR as a powerful framework and tool set for reimagining the design and practice of inclusive sports.

1.4. Motivation

Blind soccer is an inclusive sport that not only broadens access to athletic participation, but also fosters the integration of individuals with disabilities and those without disabilities. By breaking down social barriers, it enhances mutual understanding and promotes values such as equality, respect, and a shared sense of belonging within diverse communities. However, to experience blind football training, a dedicated ball with an internal bell, a complete team, and professional coaches are indispensable. These basic elements have also become obstacles for many people to participate in blind football. This limitation not only makes it difficult for individuals to train independently, but also makes it difficult for those who lack understanding of visual impairment and blind football to get involved and develop interest.

VR has the potential to play a significant role by offering realistic opportunities to experience a wide range of embodied activities. However, the current limitation lies in its predominant use as a visual medium, which makes it less suitable for delivering non-visual experiences.

The objective of this project is to design a non-visual VR experience for blind soccer that utilizes audio and haptic feedback to enhance users' understanding of the sport and improve their confidence in participating in blind soccer when in-person training opportunities are unavailable.

1.5. Research Questions and Goals

Blind soccer, as an inclusive sport, has played a positive role in promoting the integration of visually impaired people with other social groups. It not only offers visually impaired individuals the opportunity to participate in sports but also holds significant importance in fostering equality, respect, and a sense of belonging. However, the training process of this sport has certain thresholds, such as the need for specially designed bell-equipped footballs, the organization of fixed training teams, and reliance on professional coaching. These conditions become barriers for individuals to independently participate in training when lacking resources. Meanwhile, although VR technology has shown great potential in embodied activities, providing immersive participation experiences, most current systems still center on visual feedback, making it not really suitable for the non-visual information interaction requirements of blind soccer, which mainly relies on auditory and tactile senses. Therefore, this study aims to design a VR training system with audio and vibration feedback but without visual information, to provide a new possibility for the alternative option that allows people to play blind soccer independently even they do not have traditional necessary conditions.

This research is guided by these overarching goals: design a non-visual blind soccer VR experience that uses audio and haptic feedback to provide people an alternative option to understand the sport as an inclusive sport when they cannot access in person training; and improve beginners' confidence in blind soccer.

This study investigates how a fully non-visual VR system integrates spatial audio and haptic feedback to support beginners in developing the ability to judge the location of static and moving sound source in a blind soccer context.

This study also evaluates the effect of this blind soccer VR training system on improving users' confidence and understanding of blind soccer sport, with attention to the psychological factors such as self doubt and fear of failure that beginners often experience in the absence of visual information.

Last but not least, the research considers how sighted users experience blind soccer through the same fully non-visual VR interface. By immersing them in the same sensory constraints, the study examines whether such an embodied experience can foster a deeper understanding of accessibility, empathy, and the value of inclusive sports.

These research questions collectively inform the design, implementation, and user evaluation of the system presented in the following chapters. Through this investigation, the study contributes to providing an alternative option to experience blind soccer for people who cannot attend training in person.

1.6. Thesis Structure

This thesis investigates the application of virtual reality (VR) technology to blind football training, focusing on the design and validation of an inclusive VR training system. The research follows a structured progression organized into five core chapters.

Chapter 1: Introduction initiates the research by establishing foundational concepts, defining *inclusive sports* (1.1) and *blind football* (1.2). The study is then contextualized within the technological landscape by examining the *rise of virtual reality* (1.3). The core *motivation* (1.4) driving the development of a VR-based blind football training system is articulated. Subsequently, the specific *research* *questions and goals* (1.5) guiding the investigation are delineated. The chapter concludes with an overview of the *thesis structure* (1.6), providing a roadmap for the reader.

Chapter 2: Related Works critically reviews the existing literature and research that underpins this study. It begins by examining the domain of *inclusive sports* (2.1), emphasizing the principles of equitable participation. The focus then shifts specifically to *blind football* (2.2), detailing its rules, characteristics, current training methodologies, and inherent challenges. The current state and trajectory of *virtual reality development* (2.3) are examined, highlighting its potential applications in sports training. The principles of *inclusive design* and their integration within *VR systems* (2.4) are discussed. Finally, the intersection of *blind football and VR* (2.5) is explored, synthesizing previous work and identifying research gaps to position the novelty and contribution of this study. This chapter establishes the theoretical foundation for the subsequent system design.

Chapter 3: Concept Design comprehensively details the design philosophy, process, and iterative development of the proposed Blind Football VR training system. The design process is grounded in empirical insights gained through *training with the Japan Blind Football Association (JBFA)* (3.1). The core modules *basic skills training* (3.2) - including *guidance-based ball handover training* (3.2.1), *two-player guided ball-passing training* (3.2.2), and *three-player guided ball-passing training* (3.2.3) – are derived from this collaboration and inform the specifications of the VR system. The *blind soccer VR training system design* (3.3) is then presented, encompassing critical components such as *environment factors simulation* (3.3.1), *players and guidance performance simulation* (3.3.2), and *interactions and feedback simulation* (3.3.3). The supporting *system architecture* (3.4) is described, detailing mechanisms for *audience interaction* (3.4.1), technologies for *position and foot tracking* (3.4.2), and methods for delivering *real-time haptic feedback* (3.4.3). The chapter concludes with the *prototype and iteration* process (3.5), involving multiple cycles of refinement based on *user studies* conducted with the JBFA (3.5.1), at the KMD Forum (3.5.2) and with the Australian Blind Football Team (3.5.3), culminating in the development of the *final prototype* (3.5.4).

Chapter 4: Proof of Concept presents a rigorous empirical evaluation of the effectiveness and usability of the final prototype. It begins by specifying the *participant* selection criteria and demographics (4.1). The employed *methodology* (4.2) is outlined in a comprehensive way, describing the experimental procedures and evaluation metrics. The core findings from the *final user test* (4.3) are reported, documenting user interaction and performance. Subjective user experiences and feedback are collected systematically through a targeted *questionnaire* (4.4). Quantitative and qualitative *data collection and analyzation* (4.5) are performed to assess the system against the research goals. The chapter culminates in a *summary* (4.6) of the key findings, providing empirical evidence to address the research questions and support the study conclusions.

Chapter 5: Conclusion synthesizes the main contributions and results of the investigation. It summarizes the development process and reiterates the value proposition of the VR system for blind football training. Based on the Proof of Concept results, the chapter discusses the study's limitations and proposes concrete directions for *future research*, such as system enhancement, technological refinement, or broader application contexts.

Chapter 2
Related Works

2.1. Inclusive Sports

In recent years, inclusive sports programs have become increasingly recognized as a critical pathway to supporting the holistic development of students with disabilities. Jena (2024) conducted a qualitative study to examine the multifaceted impacts of such programs in the physical, social, emotional, and educational domains, offering valuable contributions to both the theory and practice of inclusive sports [2]. The research involved semi-structured interviews with a diverse group of 29 participants, including 15 students with disabilities, 6 teachers and coaches, and 8 parents. These interviews were analyzed to capture the lived experiences and perceptions of the participants involved in inclusive sports settings.

Thematic analysis identified four core benefit areas: physical, social, emotional and psychological, and educational and developmental. Physically, the participants reported notable improvements in fitness, motor coordination, and overall health. Socially, inclusive sports were found to improve communication skills, promote peer integration, and foster a strong sense of belonging. Emotionally, the programs contributed to greater psychological resilience, emotional well-being, and reduced anxiety. Educationally, the participants experienced positive developments in academic performance, life skills, and even career preparation.

In addition, the study emphasized the critical role of well-trained educators and coaches, institutional policy support, and an inclusive cultural environment in ensuring the success of such initiatives. These findings not only align with the previous literature on the benefits of inclusive sports but also offer a theoretical foundation and practical guidance for designing inclusive training systems in virtual spaces such as VR. The study also recommends expanding sample sizes, incorporating quantitative measures, and exploring long-term results to fully uncover the potential and limitations of inclusive sports programs [2].

Although inclusive sports have attracted increasing attention both in policy and practice, the concept of 'social inclusion' within the context of sports remains ambiguously defined. Addressing this conceptual gap, a recent scoping review sought to clarify the meaning of social inclusion in sport for people with disabilities by systematically analyzing the existing literature in accordance with the 2030 Agenda for Sustainable Development of the United Nations [18].

The review examined 18 selected studies and synthesized 152 statements related to the definition of social inclusion or its constituent elements. These statements were initially categorized into six main themes: policy, fundamental conditions, key elements, soft skills, field gaps, and best practices. Using semantic extraction techniques, ten keywords were identified from each theme and consolidated into 24 unique terms. These were further grouped into five overarching categories: (1) key people (e.g., coaches, facilitators), (2) key environments (e.g., schools, communities), (3) key methods (e.g., cooperative rules, assistive technology), (4) key benefits (e.g., sense of belonging, dignity), and (5) key barriers (e.g., structural discrimination, lack of resources). [18]

This synthesized framework provides not only a more operational definition of social inclusion in sport, but also actionable insights for the future design, implementation, and evaluation of programs. Importantly, the study highlights that genuine inclusion requires more than spatial coexistence; it necessitates intentional, structural design that focuses on participation, empowerment, and relational equity.

For projects like *Blind Soccer VR Training*, this clarified understanding of inclusion serves as a foundational guide in creating non-visual, multimodal interaction environments. It ensures that system design choices, ranging from spatial audio placement to haptic feedback timing, are informed by structural equity principles and inclusive participation frameworks.

2.2. Blind Soccer

Despite the growing global popularity of blind football, the factors influencing participation in this Paralympic sport remain underexplored. Richardson et al.

(2020) conducted an exploratory qualitative study adopting the International Classification of Functioning, Disability, and Health (ICF) framework to investigate the contextual factors that affect blind football participation among visually impaired high school students in Zimbabwe [19]. Through semi-structured interviews with 12 students from eight provinces, researchers identified five key themes that impact participation: access, sociocultural context, physical health and injury, social relationships, and intrapersonal beliefs and attitudes.

The findings highlight that the students experienced blind football as not only physically beneficial but also psychologically transformative, contributing to a (re)construction of identity and self-confidence. However, common barriers included fear of injury, limited access to specialized blind football facilities, and general lack of knowledge of the sport. In particular, many of these barriers were mitigated over time through continued participation and positive experiences, which in turn strengthened motivation and engagement.

This study emphasizes the importance of addressing environmental and psychological factors when designing inclusive sports systems for people with visual impairments. For VR-based blind football training systems like the one developed in this project, such insights are crucial. They suggest that designers must carefully consider accessibility, culturally relevant support mechanisms, and the confidence-building potential of gameplay to foster sustained engagement and skill development [19].

Blind soccer, as a concrete form of inclusive sports, has attracted growing attention in international academic discourse for its social value and educational significance. A notable example is the experimental program implemented at the Institut National de l'Éducation des Jeunes Aveugles (INEFJA) in France, where researchers systematically explored the inclusive potential of blind soccer in an educational context [20]. Rooted in the philosophy of non-exclusionary education, this initiative integrated blind soccer into mainstream physical education classes with the aim of enhancing the physical abilities, self-efficacy, and social belonging of students with visual impairments.

The results of the program [20] revealed that blind soccer is not just a medium of athletic training, but also a powerful platform to foster inclusive social cognition and cross-ability collaboration. In these sessions, visually impaired and sighted students trained together, with all participants wearing blindfolds, to participate in a shared sensory environment based on auditory cues, verbal communication, and spatial coordination. This approach, termed 'sensory equalization', not only increased engagement among students with disabilities but also provided sighted peers with a direct, empathetic understanding of the challenges and potentials of non-visual game play.

In addition, educators and program organizers have widely recognized blind soccer as a catalyst for promoting awareness and acceptance of diverse abilities within school systems. The study highlighted the importance of institutional support, teacher training, and environmental adaptation to support blind soccer as a long-term inclusive practice. These insights offer practical implications and contextual validation for the development of non-visual VR training systems such as the one proposed in this research.

In blind soccer, where vision is entirely absent, athletes must rely heavily on auditory cues to perceive the ball's position. As a result, the localization of the sound source becomes a critical skill for successful performance. Watanabe (2024) conducted an experimental study to compare this ability between visually impaired and sighted individuals, particularly under dynamic conditions where the ball approaches the player using the same type of bell-equipped ball used in official blind soccer matches [21].

Eighteen participants were divided into two groups: 10 sighted individuals with no blind soccer experience and eight visually impaired blind soccer athletes. Participants were instructed to press a button when they perceived that a rolling ball had reached them from one of the four directions. The researchers measured the response time error, defined as the difference between the moment the ball passed an optical sensor and the participant's button press.

The results demonstrated that although the time error increased with ball speed for all participants, visually impaired players consistently exhibited significantly smaller errors under all directional conditions. Multiple regression analysis confirmed a statistically significant advantage for the visually impaired group, suggesting better auditory localization abilities. The study attributed this advantage to both the early onset of visual impairment and the accumulation of auditory training through blind soccer practice.

This research provides empirical evidence supporting the idea that visually impaired individuals, particularly those experienced in blind soccer, develop improved auditory localization skills. These findings offer valuable information for the design of VR-based blind soccer training systems, where auditory signals must be carefully constructed to support ball tracking and spatial awareness. Incorporating realistic and directionally clear sound sources in VR environments may therefore not only improve training outcomes but also simulate more authentic match conditions for visually impaired players [21].

2.3. Current Virtual Reality (VR) Development and Statement

Virtual, augmented and mixed reality (VR, AR, MR) technologies have rapidly expanded beyond entertainment and gaming into diverse domains such as industry, engineering, retail, real estate, military, healthcare, and education. Despite this growing adoption, there remains a significant shortage of skilled developers capable of designing interactive and domain-specific XR content (extended reality) to meet practical demands [22].

To address this gap, Kajanová et al. of Matej Bel University in Slovakia examined the importance of interactivity in VR in three primary areas: gaming, healthcare, and education [22]. The study emphasizes that interactivity plays a fundamental role in shaping user engagement, emotional involvement, and behavioral outcomes in different use cases.

In healthcare, for example, the paper [22] presents an application targeting arachnophobia (fear of spiders), where participants were exposed to virtual spider environments. The interactive VR scenario was shown to facilitate gradual desensitization and user responses were evaluated using post-experience questionnaires. The findings highlight how interactivity improves therapeutic impact by allowing users to control their level of exposure and react in real time.

This research [22] underscores the importance of tailoring VR interactivity to match specific training or therapeutic goals. In the context of blind soccer VR training, these insights validate the need for carefully designed sensory engagement, especially tactile and auditory feedback, to create effective, immersive, and accessible learning environments.

2.4. Inclusive Design and VR system

Conventional VR systems are mainly based on visual information, making them largely inaccessible to users with visual impairments. Addressing this gap, Azenkot's team [23] created Canetroller (figure 2.1), a new haptic cane controller that simulates the real-world use of a white cane, allowing visually impaired users to navigate virtual environments by transferring their existing mobility skills to VR.

Figure 2.1: Canetroller

The Canetroller [23] integrates three types of multimodal feedback: (1) physical resistance, generated by a programmable wearable brake mechanism that stops movement when the virtual cane contacts a virtual object; (2) vibrotactile feedback, simulating tactile sensations when the cane strikes or drags across different surfaces; and (3) spatial 3D auditory feedback, mimicking the acoustic cues of cane interactions in physical space. This design approach allows users to maintain a consistent navigation strategy between the physical and virtual worlds, enhancing immersion and spatial awareness.

The research team evaluated Canetroller in both indoor and outdoor VR scenes. The results demonstrated that visually impaired participants were able to navigate various virtual spaces effectively, confirming the potential of the system not only in entertainment but also in practical applications such as orientation and mobility training. This work highlights the importance of multisensory feedback in VR interaction design for accessibility and provides foundational information for projects such as VR-based blind soccer training, where non-visual feedback is central to the user experience [23].

Participation in sports offers individuals with disabilities crucial opportunities for social inclusion, physical and mental well-being, skill development, and improved self-confidence. Sitting volleyball, a widely played parasport adapted from traditional volleyball, has been practiced in more than 75 countries since its introduction in 1956. However, the limited availability of dedicated sitting volleyball courts creates a substantial accessibility barrier for many aspiring athletes with disabilities.

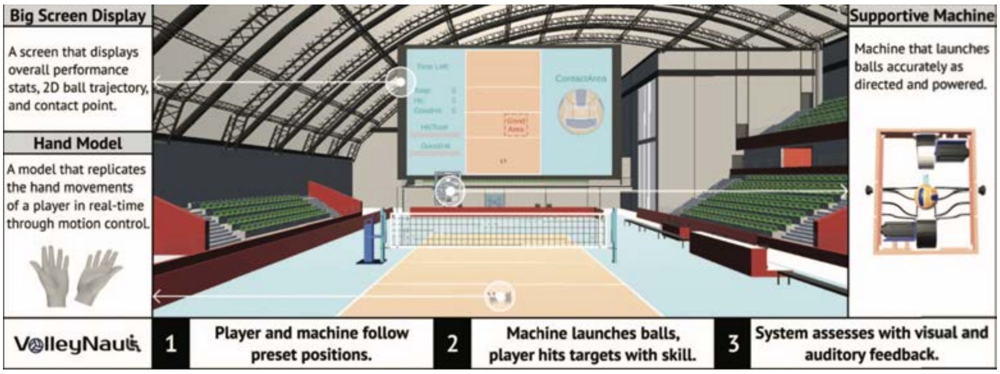

Figure 2.2: VolleyNaut

To address this challenge, Gong's team [24] developed VolleyNaut (figure 2.2), an immersive VR training system specifically designed for the inclusive development of sitting volleyball skills. Created in close collaboration with professional coaches, VolleyNaut simulates realistic ball pitches and replicates daily defensive drills through four specialized training scenarios. These scenarios are aimed at supporting the acquisition and adjustment of basic skills, particularly for amateur players who lack access to physical training spaces.

In a comprehensive user study, the researchers recruited a diverse group of participants, including collegiate and club volleyball players, national sitting volleyball athletes, and coaches, to evaluate the engagement and effectiveness of the system. Using both quantitative and qualitative methods, the study reported consistently positive feedback, highlighting the potential of the system as a viable and inclusive training tool [24].

This work exemplifies how VR can be leveraged to promote inclusive design in sports training, especially when physical infrastructure is limited. For other sports, such as blind soccer, VolleyNaut serves as a valuable precedent, demonstrating how immersive environments can help bridge access gaps while maintaining high standards of skill development and user engagement [24].

2.5. Blind Soccer and VR

As reviewed above, blind soccer is a globally expanding inclusive sport that offers significant benefits for physical health, social inclusion, and identity reconstruction among individuals with visual impairments. However, existing studies have highlighted persistent barriers that hinder participation, including fear of injury, lack of awareness, and limited access to dedicated training facilities [19]. Importantly, research has also shown that visually impaired individuals exhibit superior auditory localization abilities compared to sighted individuals, particularly under dynamic conditions that involve moving sound sources such as a rolling ball [21]. These findings suggest that well-designed auditory feedback could serve as a strong foundation for skill development in blind soccer training.

Meanwhile, the growing body of work in VR for inclusive training provides compelling precedents for addressing these challenges. For example, VolleyNaut, an immersive VR system co-developed with professional sitting volleyball coaches, successfully replicated real-world training drills and helped compensate for the lack of physical court access. It received consistently positive feedback from amateur and national players [24]. Similarly, Canetroller provided a non-visual navigation system for blind users in VR, using haptic resistance, vibration, and spatial audio to simulate white-cane interactions. The system enabled users to apply real-world mobility skills in a virtual space, offering valuable design strategies for accessible VR interaction [23]. More broadly, studies on VR's application in gaming, education, healthcare, and therapeutic contexts emphasize the central role of interactivity and multisensory feedback in shaping user experience and effectiveness [22].

Despite the proven potential of VR and haptic audio feedback in inclusive applications, there is still a significant research gap at the intersection of blind soccer and immersive VR technology. Specifically, no existing systems have systematically explored how auditory spatial cues and haptic foot feedback can be combined to support beginners in blind soccer training, particularly in a fully non-visual environment. Therefore, this research introduces a VR-based blind soccer training system using Meta Quest and bHaptics devices to simulate realistic kicking, ball reception, and directional listening tasks. The system aims to provide a safe, repeatable, and confidence-building environment for novice players, while also serving as an experimental platform to explore principles of non-visual interaction in sports training.

Drawing on the theoretical insights and empirical validation offered by prior work, this study is positioned as both feasible and necessary. It seeks to advance the field of inclusive interaction design and immersive sports training by addressing a critical gap and applying validated methodologies in a novel application area.

Chapter 3
Concept Design

3.1. Training with Japan Blind Football Association (JBFA)

Figure 3.1: Training with JBFA

To better understand the structure and experiential qualities of blind soccer, field research was conducted in collaboration with professional players from the Japan Blind Football Association (JBFA) (figure 3.1). Through field work, it was learned that blind soccer is not only for people who are completely blind; rather, it serves as an inclusive sport that welcomes players with varying degrees of visual impairment as well as sighted participants. This inclusiveness is supported by adapting the game's mechanics, in which all outfield players in blind soccer communicate through sound and hearing, a communication mechanism that ensures fairness and cooperation between those with different abilities.

The standard team composition includes four outfield players, one sighted goalkeeper, and a guide stands behind the opponent's goal for each team. Because even visually impaired people, there are various types and degrees of visual impairment and half visual and full visual people also participant, during match and training, every outfield player is required to ware an eyemask to make sure the match is fair. While goalkeeper need to be visual and do not need to ware eyemasks. Players are also required to use verbal cues such as 'Voy' to announce their positions to avoid collisions. The ball is customized with bells inside. When the ball is moving, inside bells will make sounds to let players know the position and movement state of the ball. During training, when the ball stops moving and does not make a sound, making it too difficult for outfield players to locate it, assistant people or resting players who are not wearing eyemasks and have vision will assist in going up to the ball and shaking it to make it sound again therefore outfield players can continue to locate the ball.

Direct participation in training drills provided critical insight into the perceptual and psychological demands of the sport. When performing activities such as tracking the ball, responding to teammates' calls, or trying a goal kick with the eyes closed, a noticeable disorientation appeared. Ambulation became hesitant, requiring arm extension for collision avoidance and a continuous reliance on sound to infer surrounding positions. The absence of visual reference significantly reduced spatial confidence, highlighting how physical hesitation and fear of failure can become major barriers to learning for novices.

These findings suggest that for beginners, only having technical skills is not enough to effectively participate in blind soccer. Psychological preparation is also important, especially confidence building in auditory and proprioceptive senses, as well as mutual trust between players. Therefore, design training systems for beginners should pay attention to both perceptual accuracy and emotional levels of security and support.

These empirical insights directly informed the system design of 'Blind Soccer VR Training'. The VR environment was constructed to simulate key perceptual and motor challenges identified during field training, with a particular emphasis on supporting skill acquisition in the following areas.

Directional Listening: Players can be guided by specialized audio cues, including the sound of the ball, which changes according to the state of the ball's movement to simulate the sound of the bell in the ball under different states of movement in the real world, and the direction of the virtual target, allowing users to navigate by sound without visual reference.

Ball Tracking via Sound: The virtual ball emits a dynamic spatial sound that adjusts based on movement state and position, allowing users to localize it through binaural listening and anticipate its trajectory.

Spatial Orientation: In addition to the sounds of the ball and goals, the system also plays other audio on a conditional basis, such as whether the goal is hit correctly, and the sound of the ball hitting the wall, allowing the user to understand what is happening in the scenario through sound and how their decision making has resulted in the outcome, and guiding subsequent decisions and adjustments to the action. This helps the user construct the spatial structure of the environment in their mind, and this skill is important in real blind soccer match and training.

3.2. Basic Skills Training with JBFA and Volunteers

Figure 3.2: Training with volunteers

During field research conducted with over 30 beginners under the guidance of professional athletes from JBFA (figure 3.2), it became evident that blind soccer training for beginners does not begin with gameplay or scoring. Instead, it focuses on building foundational perceptual and motor skills essential for safely and confidently navigating a non-visual environment.

Initial sessions emphasized core skills such as interpreting the position and direction of the ball and teammates using auditory cues, moving toward sound sources, and dribbling while blindfolded. Most of beginners hesitate in movements during training because of fear of tripping over the ball or stepping on the ball and falling down and getting injured.

When attempting to move with the ball while blindfolded, many beginners encounter common difficulties; due to the discomfort of being deprived of vision and the lack of experience in perceiving space in the absence of visual information, it becomes very difficult to locate the ball to pick it. In many cases, beginners will accidentally kick the ball in the process of moving closer to the ball but making it farther away. Sometimes there is also a certain lack of orientation and spatial awareness, thinking that they are about to hit the wall but are actually some distance away, or are actually moving away from the wall.

Two very different behavioral strategies emerged among the beginners during training. Some beginners followed the sound cautiously, showing hesitation because of fear of stepping on the ball and falling, and got close to the ball when it slowed down. These participants used the volume and frequency of the sound to estimate the distance and extended one foot to swipe in front of them to "detect" the ball's location, usually successfully finding it. Other beginners moved quickly in the direction of the sound, and these participants usually took large steps toward the expected location of the ball. In some cases, they stepped on the ball or inadvertently kicked it far away.

After individual training, the training changed to team exercises aimed at developing trust in teammates and the ability to cooperate. Interviews conducted during these exercises revealed that most beginners initially did not trust verbal instructions from others enough, often fearing risk of collisions or tripping. Hesitancy in moving reflects a lack of trust, not only in their teammates, but also in their own spatial judgment.

Many participants also expressed fear that incorrect decisions might result in a failed play or cost their team points, leading to hesitation and a lack of decisiveness. Despite this, the feedback also revealed a strong sense of responsibility and a shared desire to support the team, underscoring the importance of psychological preparedness in blind soccer.

Three types of training activities were conducted to support the acquisition of core competencies required in blind soccer. The first is known as 'guidance-based ball handover training', designed to help beginners build confidence in moving accurately toward a target using auditory cues provided by a teammate. The remaining two are 'guided ball-passing training', including one with two participants and another with three.aimed at improving participants' ability to determine direction based on sound and to execute accurate, confident kicks toward a verbally indicated target. All three training formats emphasize auditory spatial awareness, orientation, and motor coordination in non-visual contexts.

3.2.1 Guidance-Based Ball Handover Training

Figure 3.3: Photos of Handover Training

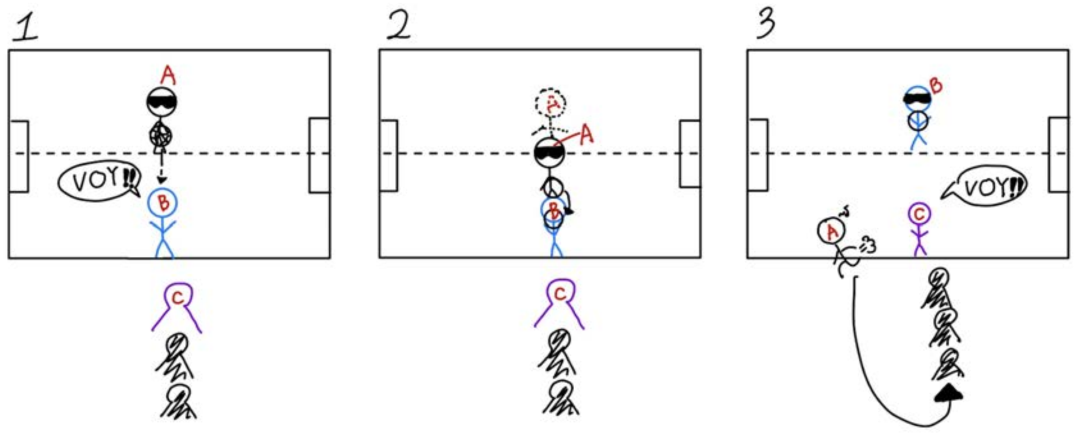

Figure 3.4: Handover training sketch

In guidance-based ball handover training (figure 3.3 and figure 3.4), two players stand on a line perpendicular to the long side of the field: Player A (guidance) is positioned at the edge of the field, while Player B (the active participant), blindfolded, starts at the halfway point. Player A provides directional signals by clapping or calling out phrases such as 'voy' to indicate their position. If Player B deviates from the correct path, Player A gives additional verbal guidance such as 'left', 'right' to help realign their direction. The training is considered successful when Player B reaches Player A's position. The two players then rotate: Player A returns to the end of the line, and Player B takes on the role of guidance for the next participant. This training helps to reinforce spatial tracking and movement confidence guided solely by auditory input.

3.2.2 Two-Player Guided Ball-Passing Training

Figure 3.5: Two-player passing ball

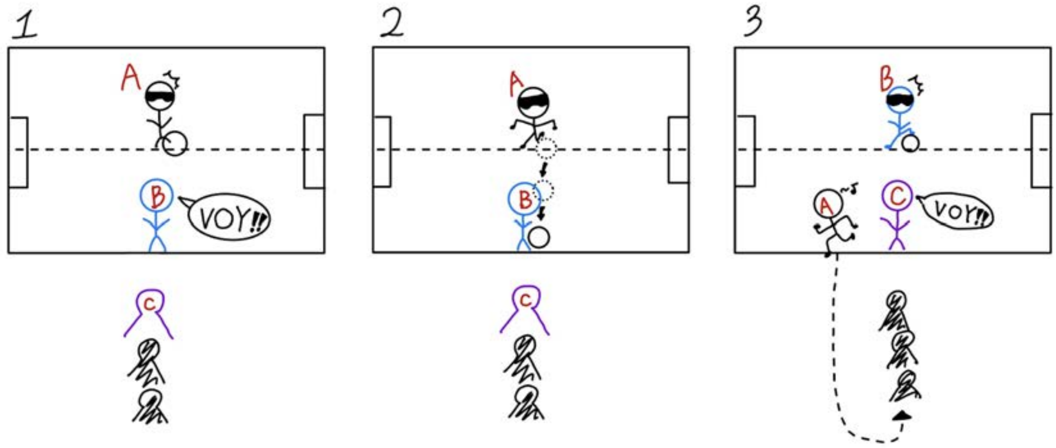

Figure 3.6: Two-player passing ball sketch

In two-player guided passing training (figure 3.5 and figure 3.6), player A (guidance) is placed on the long edge of the field, and Player B, who is blindfolded, stands at the midpoint of the field. Player A first uses auditory cues, claps or 'voy', to help Player B face the correct direction. If necessary, directional commands such as 'left', 'right' are provided to assist in orientation. Once Player B is properly aligned, Player A clearly signals that it is appropriate to kick by saying 'Shoot'. Player B then lightly kicks the ball into the position of Player A. A successful pass is defined by the ball reaching Player A. However, even if the orientation is correct, the accuracy of the pass depends on the posture and technique of the kick of Player B, both of which require repeated practice. If the ball misses, Player A retrieves it or is assisted by a sighted staff member. After each pass, Player A moves to the end of the line, Player B takes over the guidance position, and the next participant steps in as the new kicker.

3.2.3 Three-Player Guided Ball-Passing Training

Figure 3.7: Three-player passing ball

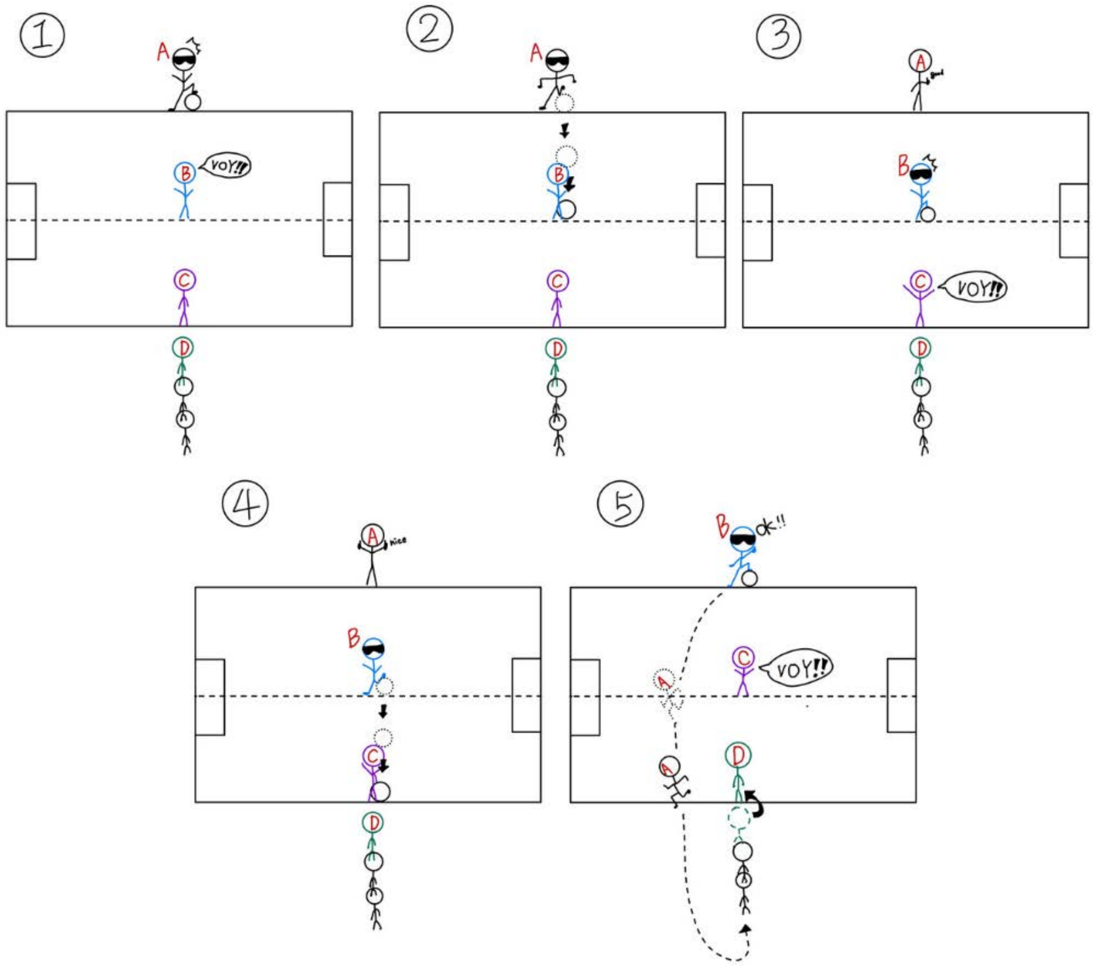

Figure 3.8: Three-player passing ball sketch

The three-person format builds upon the two-person structure by introducing a third participant (figure 3.7 and figure 3.8), Player C, who stands on the opposite long-side edge of the field from Player A. Players A, B, and C align in a straight line perpendicular to the sidelines. In this configuration, Player B serves a dual role: guiding Player C and passing the ball to Player A. The sequence begins with Player C blindfolded and Player B providing auditory guidance by clapping and calling 'voy', supplemented with fine-tuning cues like 'left', 'right' to assist in orientation. Player C then kicks the ball toward Player B, aiming to deliver it as accurately as possible. If the ball veers off, Player B or a sighted assistant retrieves it. Upon receiving the ball, Player B puts on the blindfold, while Player A assumes the guidance role and provides the auditory direction for Player B's pass. One full cycle, from Player C's pass to Player A's reception, constitutes a single round. After each round, the roles rotate: Player A moves to the back of the line, Player B replaces Player A, and Player C steps into Player B's position. The next participant then joins the group as the new Player C. The number of successful rounds is used to score each group's performance.

These structured and repeatable training activities not only target technical skill development, such as directional accuracy, passing control, and auditory tracking, but also foster trust, role-switching fluency, and group coordination in a non-visual context, all of which are critical to real-world blind soccer gameplay.

3.3. Blind Soccer VR Training System Design

3.3.1 Environment Factors Simulation

The blind soccer field follows the same specifications as a standard FIFA football pitch, and training sessions are typically conducted on similarly scaled fields composed of basic structural elements such as the ground surface, boundary walls, goal, and ball. In this project, the training environment was modeled and simulated using the Unity platform. During the modeling process, a flat plane was used to represent the ground, while resized cubes were placed along the perimeter to form rectangular boundary walls, thus constructing an enclosed training space. The goals were also modeled using cube objects to represent their basic structural form.

Considering that high-complexity 3D models significantly increase the computational load of physics-based collision processing [25], potentially compromising the real-time responsiveness and stability of system interactions, we intentionally avoided using high-resolution meshes or detailed textures in the modeling process. In this project, all user interactions are mediated through auditory and haptic channels. Therefore, enhancing visual fidelity does not contribute to the user experience and may instead lead to unnecessary consumption of system resources, which could negatively impact the responsiveness of sound and haptic feedback.

Therefore, a function-oriented modeling strategy was adopted in which the virtual training environment was constructed using simple geometric shapes. Physical properties and interactive behaviors were assigned to each object through scripted control. This approach significantly reduced system resource consumption and improved overall runtime performance. Furthermore, it better aligns with the interaction needs of non-visual users, providing a solid technical foundation for an efficient, stable, and immersive training experience.

Guide people are positioned behind the goal area, to provide verbal instructions to outfield players during training. Together with full-vision individuals who do not wear eye masks, they also serve as safety assistants, helping to prevent players with eye masks from colliding with the walls while chasing the ball or making rapid movements across the field.

Environmental factors play a critical role in both spatial perception and safety during blind soccer training, particularly in indoor settings. In real-world training scenarios, the space is typically enclosed by physical walls. When players are moving at high speed and focusing on locating the ball, especially in environments with background noise or voices from others, auditory cues may be masked, making it difficult for players to accurately perceive the proximity of boundaries. If safety assistants or guidance are distracted or do not respond in time, players wearing eye masks may misjudge their position and collide with the walls, resulting in potential injury.

Given that blind soccer is entirely dependent on non-visual interaction, players rely heavily on auditory feedback to estimate their position within the space. To simulate this aspect, the system implements sound-triggered physical collisions: When the ball hits a wall, an impact sound is generated. The volume of this sound is dynamically adjusted based on the velocity of the ball at the moment of impact: Faster collisions produce louder sounds, whereas slower impacts result in softer audio feedback. Additionally, spatial audio rendering ensures that users hear louder sounds when closer to the point of collision and quieter sounds when farther away. This auditory feedback enables users to infer the scale of the virtual training space based on the direction and intensity of the ball-wall collisions [26].

By simulating these environmental audio cues, the system helps users become familiar with how ball-to-wall collisions can indicate spatial boundaries in real-world training. This assists players in forming intuitive associations with signals such as 'boundary proximity', 'risk', and the need to 'stop movement', thereby reducing the risk of wall collisions during real matches or training sessions [27].

3.3.2 Players and Guidance Performance

Field research conducted in collaboration with the JBFA highlighted the essential role of guide people in blind soccer matches. During official matches, the guide is positioned behind the goal of the opposite team and provides auditory cues to assist outfield players in locating the goal and attaching. One common cue is the word 'Voy', which alerts players to the direction of the goal. When an outside player carrying the ball approaches the goal and prepares to shoot, the guide will call out two numbers: the first indicates the approximate distance (in meters) between the player and the goal, while the second represents the angle (in degrees) between the player's position and the goal. By interpreting these values in combination with the spatial origin of the guide people's voice, the outfield player can infer the exact position of the goal and execute a shot.

In blind soccer, guide people provide essential directional information that supports both spatial orientation and decision-making. Similarly, during field-based training sessions for beginners, guides also play an indispensable role. In basic skills training, players alternate between the roles of outfield player and guide. This rotation helps all participants develop an understanding of the specific types of information players need and how to deliver concise, clear, and effective auditory instructions. Moreover, this approach ensures fairness by allowing each participant to experience both passing and receiving drills as a player, while also learning how to support teammates as a guide.

To accurately replicate the scenario of beginners participating in basic skills training within the VR system, the primary task is to simulate the process of voice guidance of guidance to outfield players and the interactive behavior of players making movements, judging directions, and executing shots based on the guidance.

In real-world training scenarios, the guide people typically stand behind the goals or targets, maintaining a relatively fixed position with minimal movement.

The guide people's primary role is to provide verbal cues to assist players in spatial orientation and goal-directed actions, with little to no interaction beyond auditory cues. Based on this characteristic, the VR system places a virtual sound source with an Audio Source component behind the goal within the Unity scene to simulate the guide people's role. This component automatically plays the verbal cue 'Voy!' to indicate the direction of the goal and guide the user to execute a shot.

To enhance the closed-loop nature of the training feedback, the system includes a post-shot result feedback mechanism. After the user performs a shooting action, the system evaluates whether the shot successfully hits the intended target and plays the corresponding voice message, such as 'Nice Shot!' for a successful attempt, or 'wrong gate' for an incorrect one. This design effectively simulates the typical interaction flow of guide people in basic training, enabling users to receive both spatial orientation cues and immediate outcome feedback in a fully non-visual environment to improve the sense of immersion and continuity in the training experience.

3.3.3 Interactions and Feedback Simulation

This system designs a set of multimodal interaction and feedback mechanism around 'non-visual interaction experience in a full black visual environment'. It consists of three key components: motion-based interaction, auditory feedback, and haptic feedback. In the training process, the user is completely in a virtual environment without visual information, relying on auditory and tactile channels for information acquisition and action decision making.

Auditory feedback plays a central role in spatial orientation and guidance. It is primarily used to help users explore the training space, perceive the positions of the ball, teammates, and goal, and determine the outcome of their shooting attempts. Fundamentally, users infer the direction, distance, and motion state of sound-emitting objects based on auditory cues. The interaction system is therefore designed to strengthen users' ability to localize and interpret moving sound sources in a non-visual environment.

Through the use of spatial audio rendering, users can estimate the direction and distance of a target based on changes in sound directionality and volume, enabling orientation and the execution of targeted actions. In addition, the system provides immediate auditory feedback after each shot to inform the user whether the correct goal has been reached, completing a closed-loop interaction cycle of 'guidance-execution-feedback.'

However, relying solely on auditory feedback presents limitations. Specifically, when the user is in close proximity, or even in direct contact, with the ball, it becomes difficult to determine whether a physical interaction has actually occurred [28]. The user may think that the ball is nearby but is unable to confirm that contact has been established through auditory cues alone.

To solve this issue, the interaction system incorporates haptic feedback. When a collision between the user and the ball is detected, the system triggers a tactile signal. Upon perceiving this vibration, the user can clearly recognize that contact with the ball has been made.

In addition, when the system detects that the user has performed a valid kick action, haptic feedback is triggered to indicate that the ball has been successfully kicked rather than simply simulating a kicking motion. This feedback helps users understand the current stage of the interaction, making the subsequent auditory cue, indicating whether the goal was achieved, feel more contextually natural. By providing a clear and intuitive tactile signal, the system enhances the user experience under non-visual conditions, ensuring both immersion and consistency throughout the training process.

3.4. System Architecture

3.4.1 Audience Interaction

Audio Effect of Ball

Blind soccer uses a specially designed ball that contains bells inside. When the ball moves or shakes, the bells produce a sound, allowing outfield players to locate the ball based on auditory cues. To replicate this feature in the virtual environment, the system simulates the real-world blind soccer ball by attaching an Audio Source component to the 3D ball model and playing to play the sound which is recorded from the real ball to make sure the sounds are as similar as possible when people are hearing.

In real blind soccer training, when the ball stops moving, players cannot find the ball by themselves and other visual teammates who are resting or assistants will go to shake or tap the ball to make sounds and help the players find the ball. To address this situation, in the system, the virtual ball has two kinds of play modes of sound. When the ball is static, the bell sound will play with a certain frequency, while, when the ball is moving, the bell sound will be played according to the current speed of the ball. The faster the ball moves, the shorter the interval between bell sounds; the slower it moves, the longer the interval. When the ball comes to a complete stop, it reverts to a default interval suitable for a stationary state. This variation in the playback frequency allows users to infer the ball's movement speed and status.

Audio Effect of Guidance and Shoot Feedback

In real world training, players are required to actively move around the field to locate or chase the ball. During this process, various interference factors can occur; for example, other players can act as defenders to block the ball carrier from approaching the goal. In such cases, the ball carrier may no longer face the goal directly but instead approach from the left or right. Since players are typically in motion while carrying the ball, the goal can appear in front of, to the left or right of the player. In addition, beginners who wear eye masks often lack precise ball control, and the ball may sometimes roll away from the goal. While chasing the ball, the goal may appear behind the player. Without auditory cues from the guide, the player could unintentionally move farther and farther from the intended shooting direction.

For safety reasons and to prevent users from colliding with physical objects while moving indoors, the system is designed to encourage small-range movements rather than large-scale locomotion. Based on the auditory localization mechanism [29] to simulate these realistic conditions, four goals with independent audio sources are placed in the system around the player, front, back, left, and right, representing the various orientations in which a goal may appear relative to the user's position. As users rotate their bodies, the relative movement between their heads and the sound sources enables accurate directional perception, simulating real-world listening strategies used in blind soccer [29].

These audio sources are activated in a randomized sequence, simulating the voice of a guide coming from one of the four directions. The player must locate the active goal based on the guidance sound and perform a shooting action. After the shot, the system determines whether the player hits the target goal, the one currently emitting the guidance audio. If the shot is successful, the voice message says, 'Nice shoot!' will be played; if the player hits a different (inactive) goal, the system will play 'Wrong gate', indicating a directional error. If the player misses all goals and hits a wall instead, the collision sound of the ball hitting the wall will be played. This outcome replicates a common scenario in real-world training, where beginners often misjudge the direction or with some angular offsets and miss the target goal.

In addition, the sound of the ball colliding with the wall allows users to perceive the spatial boundaries of the VR training environment. This auditory feedback helps users become familiar with the way wall collision sounds convey the scale of the physical training field in real-world scenarios. Over time, users can develop sensitivity to key behavioral cues such as 'boundary', 'danger' and 'stop moving', to reduce the risk of collisions with walls during actual training sessions.

As the interaction system relies solely on auditory and haptic feedback, it may not provide sufficient clarity for researchers or assistants who observe the training sessions from a desktop interface. To facilitate quick and accurate identification of the currently active goal during observation, a visual cue was added: When a goal is activated, its color changes to red (figure 3.9), while inactive goals remain in their default gray color. Once the user successfully hits the target goal, its color returns to the default state (figure 3.10).

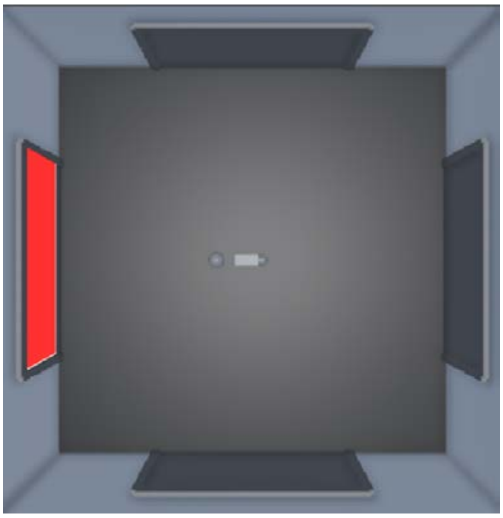

Figure 3.9: activated

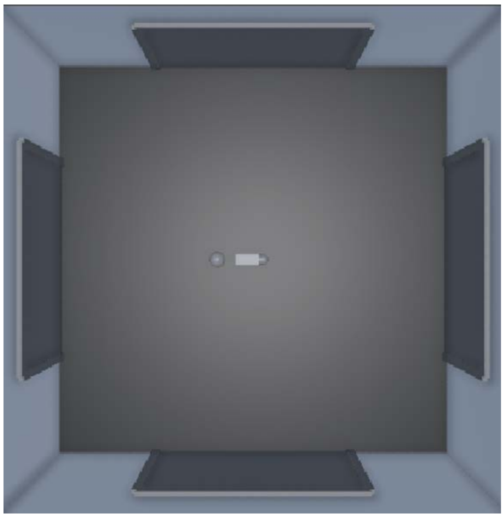

Figure 3.10: default

This visual indicator is designed solely for external observers and is not visible to users wearing the VR headset, as their display remains entirely dark. As such, it does not interfere with the non-visual interaction experience intended for the user.

3.4.2 Position and Foot Tracking

To enable natural interaction and action recognition in a non-visual environment, the system leverages the spatial tracking capabilities of the Meta Quest 3. The VR headset is used to track the user's spatial position and facing direction, while controllers are attached to the user's feet to monitor foot position and movement in real time. This setup allows the system to determine whether a kick action has occurred and to estimate the direction of the kick.

During user testing and iterative development, controllers were later replaced with Vive Trackers to improve the accuracy of foot position tracking and motion data collection. This enhancement provided a more precise and stable input for detecting foot-based interactions within the training environment.

For foot tracking, given that the ankle exhibits a simpler motion trajectory, smaller amplitude, and less susceptibility to vibration compared to the foot dorsum resulting in lower data acquisition error and considering the distinct anatomical orientations (the ankle region aligns vertically with the lower leg, while the foot dorsum presents a horizontal orientation), the handle was secured to the user's ankle proximal to the calf using straps. This positioning allows the straps to provide an effective transverse constraint during activities such as kick and stabilization of the device. In contrast, securing the handle to the horizontally oriented foot dorsum creates a misalignment between the strap's primary constraint direction and the primary potential displacement path of the device, increasing the risk of accidental detachment. VR controllers are securely attached to the user's ankles using a strap, enabling the collection of foot movement data, including changes in position in a three-dimensional spatial coordinate system forward and backward, the velocity to calculate acceleration, and the angular velocity. Using Unity's built-in physics engine, the system analyzes these motion data based on a predefined classification algorithm to determine whether the foot movement constitutes a valid kicking action, reducing miscues from turns and walks.

This approach allows the system to reliably recognize kicking behavior and trigger the corresponding auditory and haptic feedback without relying on dedicated foot sensors. Using minimal hardware components, the system delivers a functional prototype that supports the core interaction logic while maintaining simplicity in setup. This design facilitates both feasibility validation and efficient iteration during system development.

Considering that users may perform non-kicking actions such as walking or turning within the physical space, an intent-based motion analysis mechanism is designed for this system at the algorithmic level to reduce false positives. Specifically, actions aimed at adjustment of posture, such as walking or turning, tend to involve relatively smooth and gradual changes in foot velocity. In contrast, a kick motion, which carries a deliberate offensive intent, is typically characterized by a sudden and pronounced acceleration [30]. Therefore, the algorithm of this system is designed to prioritize foot acceleration monitoring as a key indicator of motion intensity when distinguishing between different types of actions.

In addition, directional differences in motion are also used to improve the accuracy of the classification. Actions such as turning typically exhibit greater components of angular velocity along the horizontal axis, whereas kicking movements tend to produce stronger angular velocity in the vertical direction. Therefore, the system integrates both acceleration and directional angular velocity characteristics in its decision-making process. A movement is classified as a valid kick action only when the foot's acceleration exceeds a predefined threshold and the angular velocity is predominantly oriented along the vertical axis.

Given the presence of individual differences, users may exhibit considerable variation in the amplitude and kicking force of the movement. During user testing, it was observed that some participants generated higher motion speeds while turning faster than others when performing actual kicks. This led to misclassification under the original velocity-based thresholding approach. As a result, foot velocity was removed as a classification criterion and replaced with acceleration and angular velocity parameters.

In addition, hardware-related problems, such as physical vibrations or signal occlusion, occasionally produced anomalous data spikes that exceeded reasonable thresholds. To mitigate the effects of such outliers, thresholds were changed from specific values to ranges, with upper and lower limits. A kick action is recognized only if the detected acceleration and angular velocity fall within this valid range.

3.4.3 Real-time Haptic Feedback

In blind soccer, outfield players rely primarily on auditory information to perceive the positions of the ball, other players, and the goal, while also receiving verbal instructions from the guide. In real-world training, players can naturally sense the presence of the ball through direct contact with their feet. However, field research has shown that most beginners, when blindfolded and searching for the ball, find it difficult to accurately determine its spatial position, particularly its distance and direction, using auditory cues alone, even when the ball is nearby. In such cases, players often extend their foot to explore the surrounding ground in an attempt to physically locate the ball through tactile contact. This behavior highlights that haptic feedback serves as a critical perceptual channel for ball localization in non-visual contexts.

The same challenge arises in VR training: When the ball is very close to the user, auditory cues alone are often insufficient to accurately determine its exact location. To address this limitation, the system provides haptic feedback at the moment of physical contact between the user's foot and the virtual ball. This design closely mirrors the interaction model observed in real-world training, where players rely on tactile confirmation to locate the ball.

Given that most haptic feedback devices operate through vibration [31], and the VR controller used in this system is strapped to the user's ankle to provide vibration feedback. This approach offers an efficient and hardware-friendly solution for replicating the tactile experience of ball contact within a non-visual training environment.

When the virtual model representing the user's foot collides with the ball model, the system immediately activates the vibration function of the VR controller to deliver real-time haptic feedback, signaling that the ball has been successfully contacted. This mechanism simulates the tactile confirmation that players receive during real-world training when making direct contact with the ball using their foot, allowing users to determine whether contact has occurred even in the absence of visual input.

Additionally, when the user performs a valid kick motion and successfully propels the ball forward, the system also triggers the haptic response to indicate that the ball has been kicked. This ensures that users can recognize the completion of the kicking interaction, even without visual confirmation, thereby reinforcing action awareness and supporting seamless non-visual interaction.

3.5. Prototype and Iteration

3.5.1 User Study with JBFA

To evaluate the feasibility of using VR to simulate basic blind soccer training and to identify key interaction elements essential to this training modality, a rapid prototype was developed. The system employs a VR headset to track the user's spatial position and facing direction in real time, while delivering spatialized audio cues. As the virtual environment is rendered completely dark through the headset, it effectively replicates the visual deprivation experienced when wearing an eye mask in real-world training.

For recognizing and responding to kicking actions, a VR controller is securely strapped to the user's ankle to collect motion data from the foot. These data are analyzed using an internal algorithm to determine whether a valid kicking motion has been performed. Upon detection, the system provides immediate haptic feedback via the controller vibration function.

The virtual environment includes four directional goals positioned along the front, back, left, and right walls of the training space. At any given time, only one goal is active and emits a prerecorded guidance audio cue, selected in a random sequence. Users must determine the direction of the currently active goal based on auditory cues, align themselves accordingly, and attempt to kick the ball toward the target. Regardless of the outcome, the system provides the corresponding auditory feedback indicating whether the shot was successful. If the user hits the correct target goal or fails to do so within 10 seconds, the system activates a new target at random and records the result in the background.

Figure 3.11: User test with JBFA

User testing was carried out in an indoor facility regularly used for JBFA training (figure 3.11), eliminating environmental variables outside and better reflecting the intended indoor usage context. Professional JBFA athletes were invited to participate, offering expert feedback and practical insight for further system refinement. *(In figure 3.11, the controller is strapped slightly above the ankle because the user requires it due to personal habits, and it has little impact on testing whether the prototype simulates the interaction of blind soccer and demonstrates the prototype's functionality.)*

Each participant participated in a three-minute kicking session during which the number of successful target hits was recorded. Before testing, researchers briefed participants on the testing procedures, including the types and meanings of audio cues, the expected user responses to those cues, and the importance of vibration feedback, ensuring a clear understanding of the system's interaction model and the test protocol.

Results

Post-test interviews with participants revealed several usability issues and areas for improvement. First, users reported that the overlapping audio cues of the ball and the target goals, coupled with their high playback frequency, created auditory confusion, making it difficult to distinguish between guidance and environmental sounds. Furthermore, the pace at which the active goal changed was perceived to be too fast; in several instances, participants had not yet located the current target before the system moved on to the next, resulting in the feeling of being rushed or left behind during the task.

Participants also noted that the duration of the three-minute test felt physically demanding. Although three minutes is a relatively short period in daily life, the continuous repetition of kicking actions without breaks led to noticeable fatigue. In contrast, real-world blind soccer training typically includes more varied activities, such as ball handling and positioning, with less frequent high-intensity kicks in such a condensed time frame. In addition, participants expressed that the system initially felt challenging to use, primarily due to unfamiliarity with the interaction flow. However, observational data indicated that most users began to adapt and demonstrate more confident and coordinated movements after approximately two minutes of engagement. This suggests that the learning curve is relatively shallow and that brief familiarization periods may significantly enhance the user experience.

Furthermore, sometimes the vibration feedback from the VR controller was described as too weak to be perceived. This issue was exacerbated by the fact that many participants wore specialized long and thick socks designed for blind soccer, which dampened the tactile sensation. As a result, some users found it difficult to notice the haptic cue intended to signal contact with the ball. These findings underscore the importance of refining the timing of audio signals, the pace of interactions, and the intensity of the haptic to improve the overall training experience.

Optimization

Based on insights gathered from user testing, several refinements were made to improve usability, clarity, and alignment of the training system with real-world blind soccer practices.

First, the playback frequency of the audio cues for both the target goal and the stationary ball were reduced to minimize auditory overload. Furthermore, the target goal's audio cue was set to a slightly higher playback frequency than that of the ball. This distinction makes it easier for users to differentiate between the two sounds. The decision also reflects real-world training scenarios, where once a player has located the ball, the most critical auditory input comes from the guidance personnel positioned behind the goal, who repeatedly shout 'goal' to indicate direction. Putting emphasis on the goal audio signal through a higher frequency signal reinforces this key direction information in the VR environment.

Second, the logic for transitioning between target goals was revised. Originally, the active goal would change upon a successful shot or after 10 seconds had elapsed. This was modified to maintain the same target until the user successfully hits it. This change allows users to focus on identifying and aiming for the active goal without feeling rushed or disoriented by sudden transitions.

Third, the overall structure of the session was redesigned. The original three-minute continuous test was replaced with a more user-friendly format: a two-minute practice phase to help participants become familiar with the system and its interaction model, followed by a one-minute formal test phase to record performance. This adjustment helps mitigate physical fatigue and reduces the learning barrier for first-time users.

Lastly, to address the issue of weak vibration feedback reported during the testing, the system replaced the VR controller with a professional haptic feedback device, bHaptics. This device is connected to the computer via Bluetooth and imported into Unity as an asset. This upgrade delivers stronger and more consistent tactile feedback, ensuring that users can clearly perceive touch interactions even through thick training socks or during dynamic movements.

These modifications collectively enhanced the intuitiveness of the system, reduced the cognitive and physical load, and brought the virtual training experience closer to the dynamics of blind soccer in the real world.

3.5.2 User Study in KMD Forum

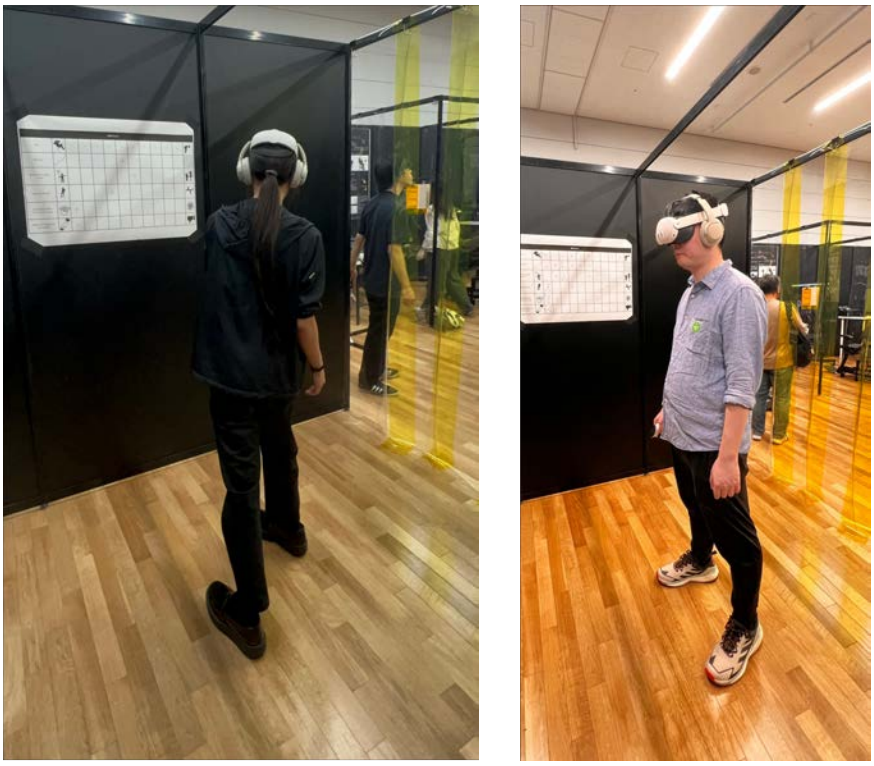

Figure 3.12: User Study on KMD Forum

During the 2024 KMD Forum (figure 3.12), we hosted eight participants who expressed interest in our blind soccer VR training project. Each participant was invited to experience the system and provide feedback. Based on insights from our previous session with JBFA professional players, we optimized the training flow to improve usability. For example, the session structure was redefined to allow participants to understand the tasks more gradually and clearly.

Due to time constraints between development phases, we were unable to fully integrate the bHaptics foot devices for this session. As a result, the system continued to use vibration from the VR hand controllers to simulate kicking feedback.

Data Collection and Analyzation

Figure 3.13: Questionnaire from KMD Forum User Study

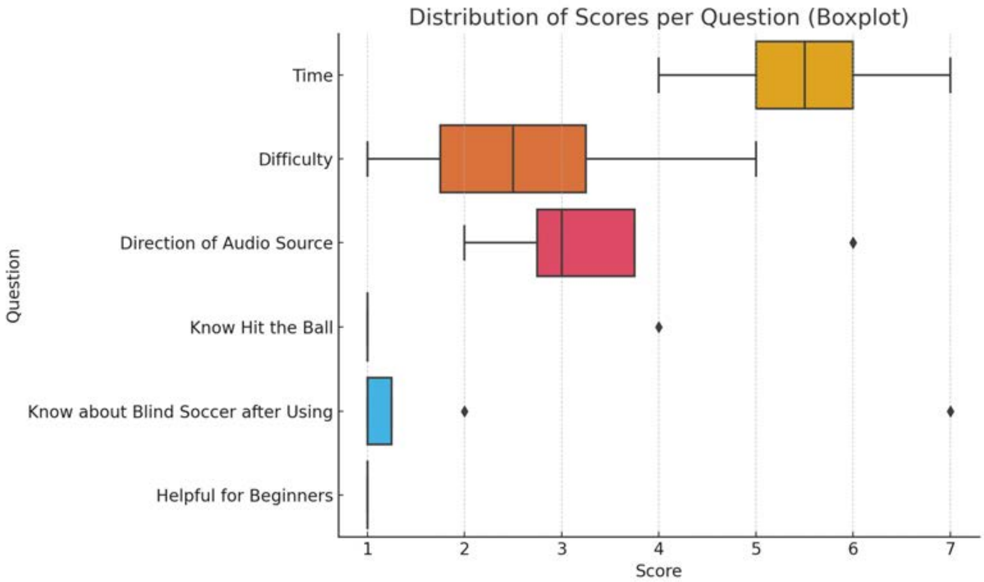

Figure 3.14: Data Analysis of KMD Forum Questionnaire

In the KMD forum, questionnaires were set up to collect participants' evaluations of this prototype and analyze them. The user experience questionnaire was in the form of a Semantic Differential Scale to assess the participants' subjective perception of the training system. Unlike the traditional Likert scale, in which "1 means totally disagree and 10 means totally agree", each item in this questionnaire was set with adjective groups with opposing meanings at both ends of the scale, such as "relaxed - tired", "easy - difficult", etc. The questionnaire was designed to assess the participants' subjective feelings towards the training system. and "easy - difficult". Participants rated between 1 and 10 to express their biased feelings based on their personal experience.

Considering that this user test is open to the whole society and some people may not be good at English, Japanese or Chinese, in order to minimize the reading burden caused by the language barrier, the questionnaire is designed with graphical expressions instead of verbal expressions, which can make the questionnaire easier to be understood by children, foreign language speakers, and people with limited literacy skills.

Following are the data captions and analysis of the box plot (figure 3.14) from left to right

Time: Although the training structure was restructured and optimized, most of the participants felt that the duration of the 3 minute experience was relatively long and could induce fatigue, especially due to repeated kick motions.

Difficulty: The difficulty of the task was generally considered appropriate. Despite having no previous experience with blind soccer, all participants were able to complete the required tasks such as identifying the correct gate and executing the kicks.

Direction of Audio Source: Six participants reported that the simulated audio provided clear direction guidance. However, two participants mentioned difficulty distinguishing direction from sound; notably, one of them explained that they were generally insensitive to auditory directionality even in real-life situations. This highlights the need for an adaptable audio calibration based on individual perceptual capabilities.

Know Hit Ball: Seven participants indicated that they could clearly perceive ball contact and kicking actions through the hand controller vibrations. However, a participant did not notice the haptic signals, suggesting a need for improved intensity or clearer feedback cues in future versions.

Know About Blind Soccer After Using: After using the system, seven out of eight participants stated they gained a clear understanding of what blind soccer is. One participant remained uncertain immediately after the experience, but gained clarity following a brief explanation.

Helpful for Beginners Start: All participants agreed that the system was helpful for beginners in introducing blind soccer in an accessible and understandable way.

Summary and Optimization

A second round of user testing at the KMD Forum enhanced the system's potential as an accessible educational tool for introducing blind soccer to beginners. Inexperienced participants were able to perform core tasks such as recognizing directional audio cues and executing kicking motions after only a short period of adaptation. The results indicate that the system has good learnability and a low barrier to entry.

Although most users reported being able to locate the direction of the goal through acoustic information, individual differences in auditory sensitivity due to congenital or acquired causes suggest that there is room for optimizing the spatial effects of audio. While the majority of participants indicated that they knew they had kicked the ball through vibratory feedback, there was still feedback that the clarity and strength of the haptic signals could be improved.

The duration of the experience, though effective in demonstrating the capabilities of the system, was perceived by several users as physically demanding, especially given the continuous foot kick actions.

Overall, these findings validate that the core design of the system is feasible and also provide actionable insights for refining the system.

3.5.3 User Study with Australian Blind Football Team

To further validate the usability and effectiveness of the training system, additional user testing was conducted with blind professional soccer players from Australia. The test location was the lobby of the hotel where they stayed during their training in Japan. As there was low foot traffic, the test was conducted without disturbing other guests and there was enough space for safe interaction.

The prototype used in this session was an updated version that incorporated the bHaptics foot devices to deliver vibration feedback, replacing the use of VR controllers for haptic output. The controllers were retained solely for positional tracking, strapped to the users' feet (figure 3.15).

Figure 3.15: controller with bHaptic

The test tasks followed the same structure as the earlier training sessions: The participants relied solely on spatial audio cues to identify the direction of the goal and the position of the ball and then performed shooting actions based on auditory guidance. The entire experience took place in a completely dark virtual environment, simulating the non-visual conditions of real blind soccer training.

Despite being conducted in a non-laboratory setting, the test proceeded smoothly. The participants gave positive feedback, noting that they could quickly understand the logic of the interaction and that the audio and vibration feedback was effective in supporting spatial localization and decision making, the system successfully captured the core elements of blind soccer training and could be used as a relevant and realistic practice tool across different training backgrounds. What needs to improve is more interactive content.

3.5.4 Final Prototype

Based on insights and feedback collected from multiple rounds of user testing, including testing with JBFA professional blind soccer players, society visitors on the KMD Forum, and athletes from the Australian national team, the final prototype was designed to add more interaction.

This version adds the catch ball function, which adds new interactive content to the original shooting content. Participants are no longer limited to identifying the direction of the goal in the virtual environment and then shooting, instead, the users are required to perceive the virtual ball's position, direction of movement, and other factors based through the auditory cue made by the ball in the virtual environment, attempt to catch the ball, and kick the ball back after catching the ball (figure 3.16).

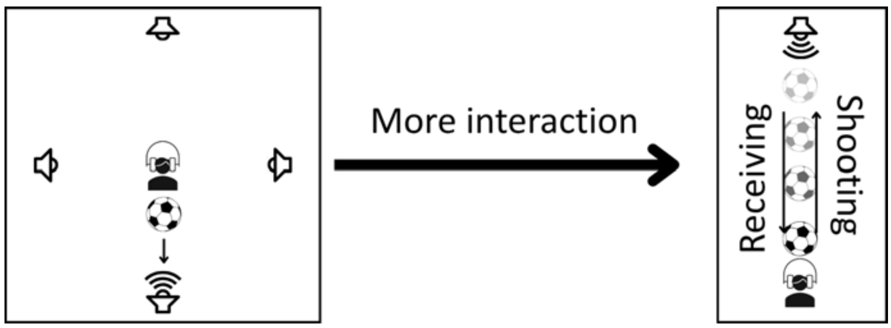

Figure 3.16: catch and return

The ball is launched from the starting point within a front oriented sector, with randomized angles confined to a forward arc (the angle a in figure 3.17) relative to the player's position. This directional constraint ensures the ball travels primarily toward the user while excluding lateral and rear directions from the start point, requiring players to perceive the position and movement of the ball and move to catch the ball.

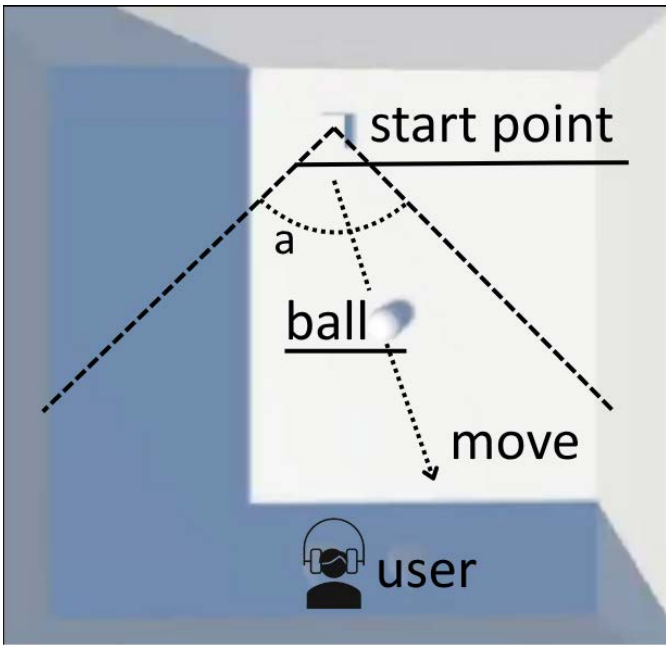

Figure 3.17: ball movement sketch

According to the sound played by the virtual ball and the start point, players need to judge the position of the start point to know where the ball is launched from (figure 3.18), and also need to judge the position and movement state of the ball and then catch the ball and shoot it back to the orientation of the start point (figure 3.19), but not strictly required to hit the start point.

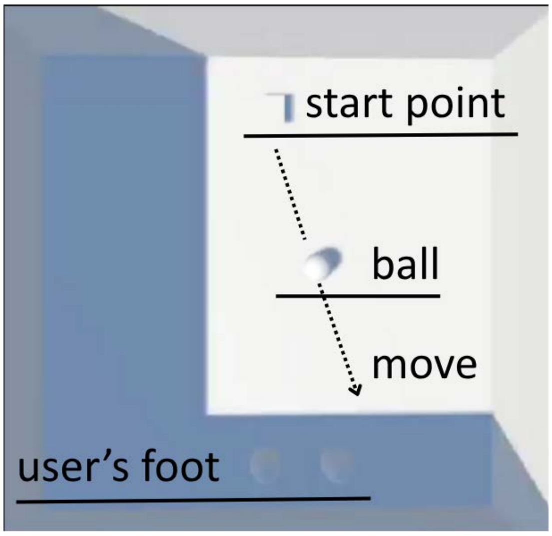

Figure 3.18: launch ball

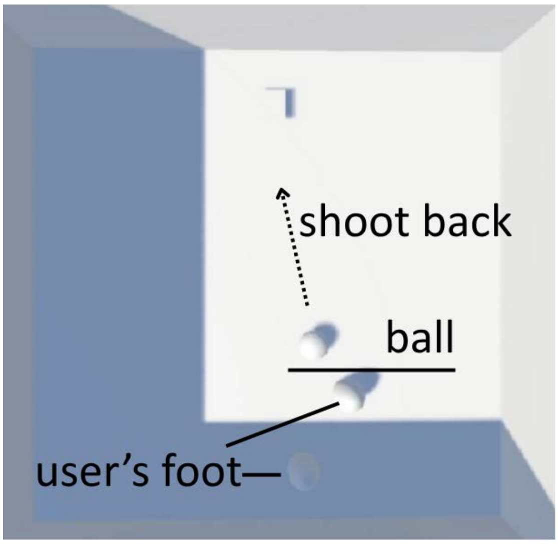

Figure 3.19: catch and shoot back

In this prototype, the sound playback logic and sound materials of the virtual ball continue the design of the previous version, using sounds recorded from real blind football as audio materials. The static or dynamic state of the virtual ball and the movement speed will affect the playback frequency of the sound, while the volume of the sound is influenced by the position of the ball in the virtual space and the spatial audio effect received by the user. Both when the user catch the ball and pass the ball back, the user will get a vibration feedback, in this way, the user can know he or she has caught or shot the ball.

To further improve foot tracking accuracy, instead of binding VR controller on the bHaptic foot device (figure 3.20), Vive Tracker devices are integrated (figure 3.21), allowing a more precise spatial location of user foot movements. Vive trackers work with base stations and connect to Unity through SteamVR.

Figure 3.20: previous prototype

Figure 3.21: final prototype

With these modifications and optimizations, this prototype provides users with a system with more interactive actions. Instead of only determining the orientation of goals and shooting the ball to the goal, a single interaction with static objects, this prototype system represents an iterative improvement by enabling users to perceive the position and motion state of a moving object through auditory feedback.

Chapter 4
Proof of Concept

4.1. Participant

This study involved four rounds of user testing, each targeting participants with different backgrounds to ensure a comprehensive validation of the system's realism, usability, and cultural adaptability.

The first round of tests was conducted with professional blind soccer players from the Japan Blind Football Association (JBFA). As experienced athletes actively involved in professional training and competition, these participants were able to provide expert feedback on the system's training logic, task design, and interaction mechanisms. Their input played a crucial role in verifying that the project accurately simulates actual blind soccer training rather than approximating generic movement-based games. This phase primarily focused on validating the correctness and authenticity of the interaction design, establishing a solid foundation for subsequent iterative improvements aimed at refining realism, clarity of feedback, and immersive experience.

The second round of tests took place during the 2024 KMD Forum, where participants were randomly recruited from the general public. Most of them had no previous experience with blind soccer, virtual reality, or sports related to disabilities. This round was designed to evaluate whether the system is beginner-friendly and understandable without expert guidance. It also served to validate the broader goals of the project: to help beginners build confidence and foundational skills and to raise awareness about blind soccer among the general public.

The third round involved professional athletes from the Australian National Blind Soccer Team. These participants provided feedback on the system's training content and interaction cues from a different cultural and training background.

This test was essential to evaluate the cross-cultural applicability of the system: specifically, whether players outside Japan, with different coaching styles and training experiences, could also interpret the signals correctly and perceive training tasks as relevant to their professional practice.

The final user test recruited participants from a diverse range of disciplines and cultural backgrounds, including product designers, front-end engineers, and art students. The group included native Chinese, English, and Korean speakers. This test was designed to assess whether the system could provide a consistent interpretable and effective training experience among different types of users. It also provided insight into the accessibility of multimodal interaction of the system, particularly how users perceived and understood the combined use of spatial sound and haptic feedback. These final stage findings were used to evaluate the system's overall usability and cultural adaptability.

4.2. Methodology

To ensure that the system design accurately reflected the structure and challenges of blind soccer training, this study began with field observations and contextual research. I visited the JBFA training site and observed their daily training routines. These sessions included not only professional athletes engaged in high-intensity drills, but also novice participants from companies and community organizations who were integrated into the same training framework. Under the guidance of professional coaches, these beginners practiced fundamental skills such as auditory localization and spatial navigation without vision.

Through multiple on-site visits and detailed documentation, I developed a deep understanding of the core competencies required in blind soccer, with particular emphasis on how professionals train newcomers. During training, beginners often showed hesitation, lack of confidence, fear of colliding with others, and unfamiliarity with the interpretation of directional audio cues. As a result, the focus of this project was defined as a training system designed specifically for beginners. This direction was also aligned with current technological limitations: the fast and complex movements of professional players are difficult to capture and simulate with current-generation VR hardware, whereas virtual environments are well-suited to support structured, repetitive training for novices to build confidence and improve basic skills performance.

The system development followed an iterative design–test–refine approach. Based on insights from field observations, I created an initial prototype using a VR headset and controllers. A controller was strapped to the user's foot to track kick movements. I then invited professional blind soccer players to test this early version and collected their feedback on training logic, audio guidance, and motion feedback design.

In the initial prototype, a VR controller was strapped to the user's foot to serve as both a motion tracker and a provider of vibration feedback upon kicking. However, during the first round of tests with JBFA professional players, several participants noted that the vibration provided by the controller lacked realism and was insufficient to confirm whether a kick had been successfully executed. This issue was especially pronounced when users wore thick socks, which further dampened the sensation.

In response to this expert feedback, a major revision was implemented: the vibration feedback previously handled by the controller was replaced with bHaptics footworn haptic devices, capable of delivering more precise and localized tactile feedback. To retain the motion-tracking functionality, the original controller remained strapped to the foot, but was used solely for positional tracking, while all haptic output was rerouted through the bHaptics system.

This hardware enhancement was positively received in subsequent user tests. During the KMD Forum test, where bHaptics was not yet deployed due to time constraints, the system continued to rely on controller-based vibration. Although most of the users were able to understand the flow of the interaction through sound and movement cues, some noted that the haptic feedback was not strong enough to be clearly perceived, reinforcing the need for a more robust tactile solution.

In the Australian National Team user test, where the updated bHaptics setup was included, the participants reported that the feedback felt significantly more realistic. In particular, the localized vibration when touching the ball increased their confidence in the accuracy of the system's responses. These cross-cultural responses suggest that the use of foot-worn haptics not only improves immersion but also enhances the clarity and reliability of interaction cues for a diverse user base.

In the final user study, which included participants from backgrounds such as product design, front-end development, and the arts, most of whom had no previous exposure to blind soccer, the integration of bHaptics helped compensate for the absence of visual feedback. Participants described the tactile signals during kicks as clear and informative, offering immediate confirmation of physical actions. This contributed to a more confident and intuitive experience for beginners, supporting the system's goal of building skills and trust in a completely non-visual training environment.

4.3. Final User Test

To evaluate whether the system can serve as an alternative method for experiencing blind soccer, a comparison test is designed, using the final prototype.

Sixteen participants from diverse cultural and professional backgrounds were recruited randomly. These sixteen participants do not have previous experience with blind soccer, aligning with the intended beginner user base of the system.

Randomly assign participants to two groups under the assumption that participants of similar levels will not be placed in the same group to perform the comparison test with two different flows. The group that performs the user test with the VR training system developed in this project is called the *Variable Group*, while another group that performs the user test without using the VR training system is called *Control Group*.

Participants in both the variable group and the control group need to complete two sets of physical tasks, and the data of each set of tasks will be independently recorded. In the variable group, participants will use the prototype for 5 minutes between the two sets of physical tasks, while in the control group, participants will rest for 5 minutes during the two sets of physical tasks.

In the **physical task** and **virtual training**, participants will work in pairs to complete physical tasks and perform virtual training. Each participant was asked to wear an eye mask to ensure that they could not see anything and could not obtain visual information during physical tasks and virtual training. In the task, participants need to finish a pass and receive tasks using a real blind football.

For the **physical task**, two participants start from standing approximately two meters apart and wear blindfolds to simulate non-visual conditions. Participants can move after the physical task starts and no longer have to deliberately maintain a distance of two meters. Throughout the task, both participants continuously called out "Voy, Voy" to help each other determine their relative positions. One participant acted as the passer, using the receiver's voice as a directional signal to guide the kick. The receiver relied on the voice of the passer and the sound of the ball to estimate its trajectory and location, moving accordingly to intercept it. Upon a successful reception, the receiver became the new passer and returned the ball using the same process.

A pass is considered successful if the ball is directed toward the receiving participant, regardless of whether the receiver successfully caught it (figure 4.1). If the ball is kicked in an incorrect direction, the pass will be deemed unsuccessful and the same participant will attempt the pass again (figure 4.2). A reception will be considered successful only if the receiver intercepted the ball. If the pass is successful, that is, directed toward the receiver, the roles will switch and the receiver will become the new passer, regardless of whether the reception was successful.

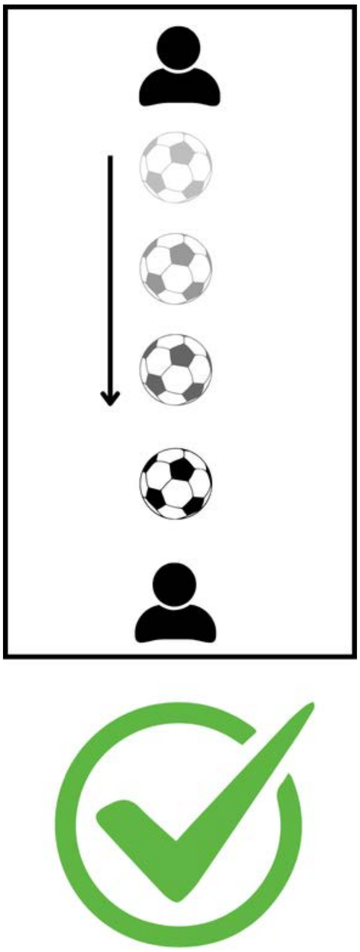

Figure 4.1: successful pass

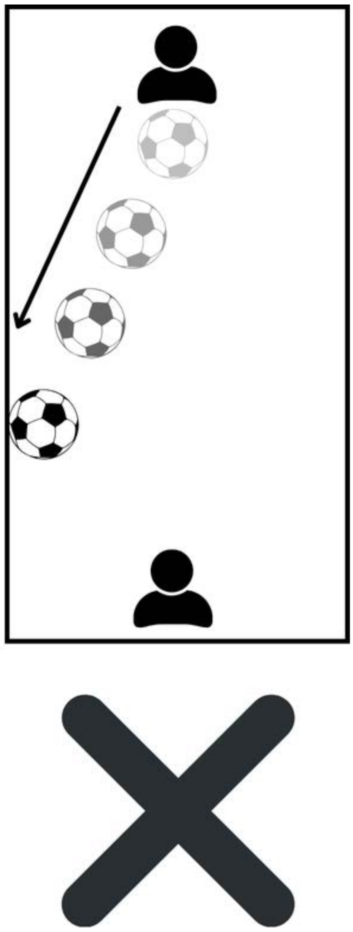

Figure 4.2: fail pass

For each participant, the following metrics were recorded independently during each physical task:

- **Total number of passes attempted**
- **Number of successful passes**
- **Total number of receptions attempted**
- **Number of successful receptions**

This task provided an initial measure of participants' ability to communicate, locate sound sources, and coordinate movements without visual input, serving as a comparison point between the pre-test and the post-test evaluation.

As for **VR training**, to ensure that users cannot obtain visual information, the virtual environment of the system seen by users will be completely black and each user puts on an eye mask before wearing the headset to ensure that they cannot see anything even through the gap between the headset and the bridge of their nose. In VR training, the ball will be shot from the start point at a random angle to the side where the user is, the user needs to listen to the sound to determine the position of the ball and the direction of movement, and then move towards the ball to catch it (figure 4.3) and shoot the ball backs (figure 4.4).

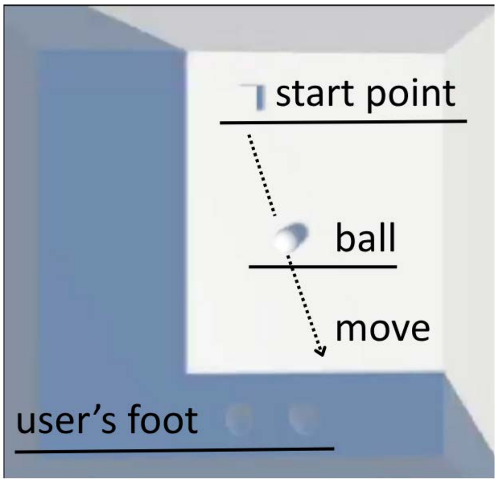

Figure 4.3: catch

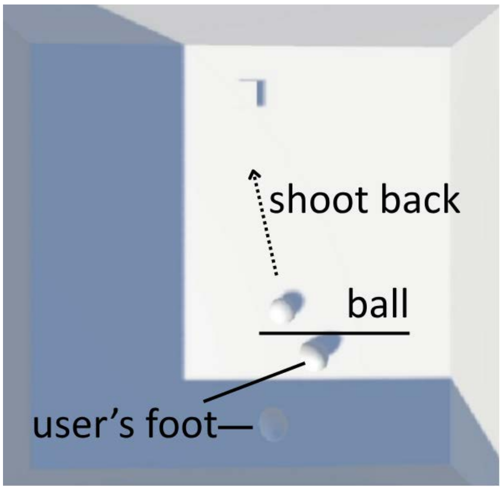

Figure 4.4: shoot back

Users receive vibration feedback from the bHaptic foot device when they catch the ball and when they shoot the ball.

This comparison test consists of the *introduction*, *pre-test*, *comparison part*, and *post-test*. For the variable group, the comparison part is using the Blind Soccer VR Training system around 5 minutes; as for the control group, participants are asked to have a 5-minute rest. By setting whether using the final prototype of the Blind Soccer VR training system as the variability, according to the data collected from two groups, the effect of the physical task can be excluded and the impact of the VR training system can be analyzed.

During the **introduction** session (figure 4.5), participants were given a comprehensive overview of the project, the system, the virtual environment, and the devices,including the real blind football, to ensure they fully understood the purpose of the project, how the system operated, the user experience during interaction, the types of interactions involved in the test, what feedback they might receive as participants, and the appropriate responses to take when receiving instructions or feedback.

Figure 4.5: introduction

Following the introduction phase, participants proceeded to the **pre-test** part (figure 4.6). During this stage, participants were first required to complete a pre-questionnaire assessing their understanding of blind soccer, self-confidence in movement without vision, prior sports experience, and previous exposure to VR technology. Upon completion of the questionnaire, participants performed the physical task involving a real blind football, during which their performance metrics were recorded. Each participant, whether in the variable group or in the control group, was required to complete a total of ten shooting attempts, and the physical task was considered complete once both participants in each pair had completed their ten shooting attempts.

Figure 4.6: pre test

After the pre-test phase, participants in the variable group proceeded to the 5-minute **VR training** session (figure 4.7). In this session, participants were equipped with eyemasks, VR headset, and bHaptics foot devices with integrated Vive trackers to carry out VR training and stood in the same position as the beginning of pre-test. In VR training, participants also trained in pairs and continued to say "Voy" to simulate real blind soccer training. While, for the participants in control group, they were asked to have a 5-minute rest.

Figure 4.7: VR training

Finishing VR training session, participants were asked to complete the physical task again as the **post-test** and their performance metrics were also recorded (figure 4.8). As same as in pre-test, every participant was required to complete a total of ten shooting attempts, and the physical task was considered complete once both participants in each pair had completed their ten shooting attempts. After completing the physical task, participants of variable group also needed to complete a post-questionnaire assessing their subjective perceptions of the VR training system.

Figure 4.8: post test

This user study acquired both quantitative and qualitative feedback to evaluate the potential of the system to be an alternative option to people who want to experience blind soccer training at the beginner level but do not have the right blind football, a team or a coach.

4.4. Questionnaire

To assess the impact of the system from both cognitive and experiential perspectives, a two-part questionnaire was designed and administered: one before and one after VR training. The goal was to evaluate background knowledge, perceptual abilities, system usability experience, and perceived training effectiveness of participants using a combination of Likert scale ratings and open questions.

The **pre-questionnaire** focused on the prior exposure of the participants to blind soccer, sports experience, non-visual interfaces, and multisensory navigation. It consisted of items on the 10-point scale (1 = most negative, 10 = most positive) and included the following aspects:

- **Background and familiarity:** gender, age, understanding of blind soccer, and whether they regularly interact with visually impaired individuals.
- **Perceptual strategies:** experience with using auditory cues for spatial direction, vibration-based interaction, and confidence in interpreting tactile cues.
- **Confidence in non-visual tasks:** comfort level in performing actions without vision, and self-assessed readiness for blind soccer training.
- **System familiarity:** experience with using VR devices and belief in the effectiveness of sound cues in guiding physical actions.

The **post-questionnaire**, administered after the physical task in post-test, was designed to assess participants' subjective perceptions of the system. It included 7 Likert scale questions and two optional open-ended items:

- **Understanding and confidence:** improvement in understanding of blind soccer, confidence in non-visual tasks, with help from the VR training system.
- **System evaluation:** comfort and immersive experience of the system; whether the system is helpful and useful.
- **Social impact:** willingness to support visually impaired communities.

This questionnaire design allowed the study to capture both objective reflections and subjective insights, provides data for system evaluation and subsequent development by understanding the user's experiential background and subjective perceptions of the system. [1]

1 See attached CSV files for full pre- and post-questionnaire.

4.5. Data Collection and Analyzation

4.5.1 Comparison analyzation

From the comparison test, metrics from physical tasks in both pre-test and post-test and qualitative feedback were acquired from all participants to evaluate the impact of the VR training system. To determine whether the system of this project has benefit to users' performance in playing blind soccer, an independent samples t-test to compare improvement scores between the control group and the variable group was conducted. In addition, the results is visualized using box plot and scatter plot to examine the distribution of performance gains and the potential relationship between initial skill levels and the degree of improvement. The qualitative feedback was visualized to analyzed whether this system can provide a useful alternative option for people who want to experience blind soccer but do not have the condition. The qualitative feedback was also analyzed to evaluate whether this system can help people improve understanding of blind soccer sport and their confidence.

To evaluate whether the Blind Soccer VR Training system has a beneficial effect on users' performance in playing blind soccer, the difference between the post-test and pre-test success rates (post - pre) for each participant was calculated, followed by conducting an independent-samples t-test and computing the corresponding p-value.

As the sample size of each group is small, before conducting the significance test, the normality of the improvement scores (Post - Pre) was assessed for both groups using the Shapiro-Wilk test.

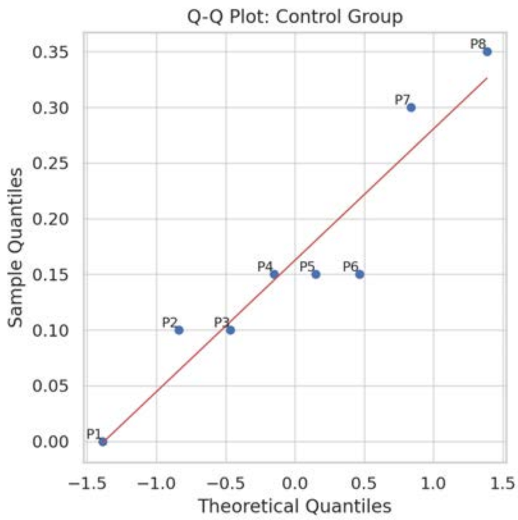

Figure 4.9: control group normality assess

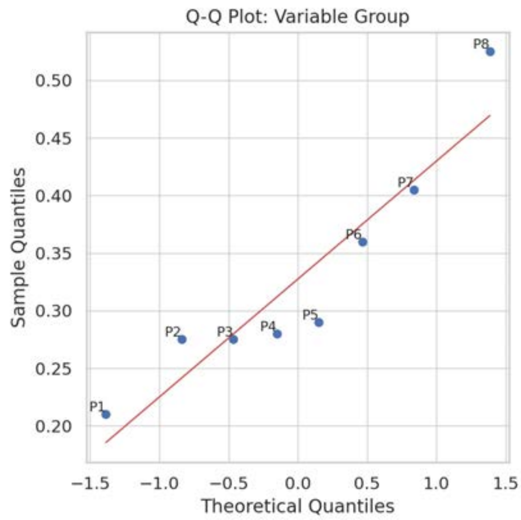

Figure 4.10: variable group normality assess

The Shapiro-Wilk test statistic W is calculated as:

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where $x_{(i)}$ is the i-th order statistic, $\bar{x}$ is the sample mean, and a_i are constants derived from the expected values of order statistics of a normal distribution. The p-value is derived from the distribution of W under the null hypothesis (that the sample comes from a normal distribution). The closer W is to 1, the more likely the data follows a normal distribution and if the p value is larger than 0.05 the null hypothesis will not be rejected, indicating normality.

In figure 4.9 and figure 4.10, the horizontal axis represents the theoretical quantification assuming a standard normal distribution, and the vertical axis represents the actual categorical delta value for each participant. The P1-P8 labels are used to differentiate between individuals and identify whether there are points overlapped. From these two figures, he data points mostly fall along the reference line, indicating that the sample distributions are approximately normal. In addition, the Shapiro-Wilk test yielded W = 0.907 and p = 0.336 for control group and W = 0.885 and p = 0.209 for variable group. Since both p-values are above the 0.05 level of significance, the assumption of normality cannot be rejected, and the data can therefore be considered as conforming to a normal distribution. Therefore, parametric methods such as Welch's t-test can be applied in subsequent analyses.

Employed Welch's t-test [32], which does not assume equal variances and adjusts the degrees of freedom accordingly. This method is more robust for analyzing real-world experimental data. In addition, the test was two-tailed, meaning it assessed whether the variable group performed significantly better or worse than the control group. Therefore, the p-value was computed with the two-tailed cumulative probability of the t distribution.The p-value is calculated using the cumulative distribution function (CDF) of the t distribution as follows:

$$p = 2 \cdot (1 - F_t(|t|))$$

- $|t|$ is the absolute value of the calculated t-statistic, which quantifies the standardized difference between the group means.
- F_t is the CDF of the t-distribution.
- The multiplier 2 accounts for the two-tailed nature of the test.
- df (degrees of freedom) is calculated based on the sample sizes and variances of the two groups (according to Welch's approximation [32] when variances are unequal).
- p is the resulting probability, which helps determine whether the result is statistically significant (typically if $p < 0.05$).

While the t value was calculated with the following function:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

- $\bar{X}_1$, $\bar{X}_2$ denote the sample means of the two groups (e.g., mean improvement: Post - Pre).
- s_1^2, s_2^2 represent the sample variances of the two groups.

- n_1, n_2 are the sample sizes of the two groups.
- t is the resulting t-statistic, used to assess the likelihood that the group means are significantly different.

Calculated with above functions, the following results were got and visualized:

Table 4.1: Statistical Summary of Performance Improvement

Metric	**Control Group**	**Variable Group**
Mean Performance Improvement (Δ)	16%	33%
Participants Showing Improvement (%)	88%	100%
t-test Result	$t = 2.27$	$p = 0.0318$

(Δ = Post − Pre)

The t statistic quantifies the difference between the means of two groups relative to the variation within the data. A larger t value indicates a more substantial difference between group means, taking into account sample size and variability.

The p value represents the probability that the observed difference or a more extreme one could have occurred under the null hypothesis (i.e., assuming there is no real difference between groups).

A larger t value suggests a stronger difference between groups, and a smaller p-value (typically below 0.05) provides statistical evidence that the observed difference is unlikely to have occurred by chance. In this comparison test, the calculated $t = 2.27$, $p = 0.0318$ (table 4.1), which indicate participants in the variable group, who trained with Blind Soccer VR Training system, achieved a greater improvement in performance compared to participants in the control group.

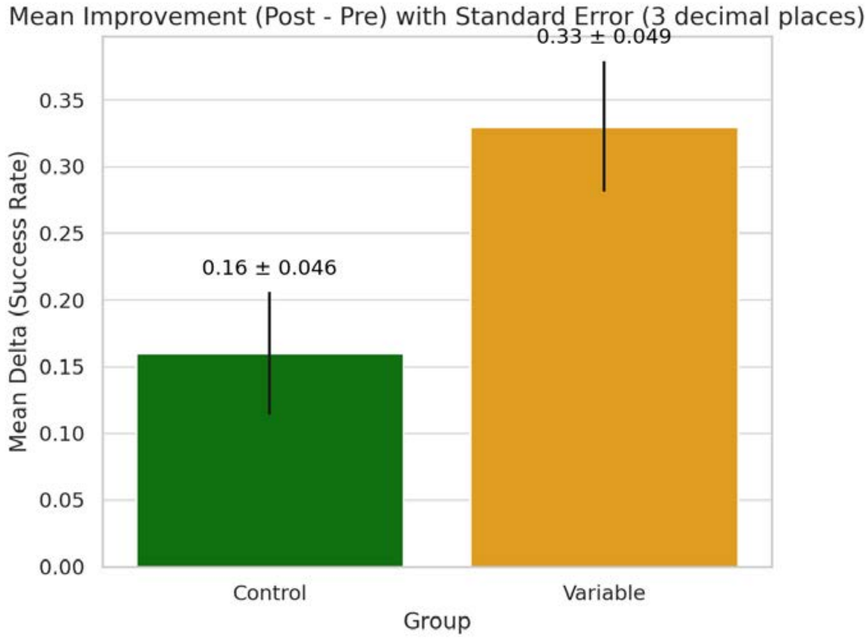

Figure 4.11: improvement in success rate

To visually support the results of the Welch's t-test, a bar chart (figure 4.11) was constructed to illustrate the average improvement (Post - Pre) in performance for both groups, with error bars representing standard error (SE).

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

SD: Standard Deviation

$$SE = \frac{SD}{\sqrt{n}}$$

Compared to control group (0.16 ± 0.046), variable group (0.33 ± 0.049) shows higher improvement. The error margin of ± 0.046 and ± 0.049 indicates the SE of the mean, which reflects the estimated precision of the group mean (i.e., how much the sample mean is expected to vary if the experiment were repeated).

Using SE rather than SD provides a clearer visual indication of the confidence in the mean values, which aligns with the statistical emphasis of the t-test. While both groups had similar SE, the variable group shows a higher overall mean, indicating that the improvement is statistically meaningful.

4.5.2 Shooting and receiving separate analyzation

To deepen understanding of influence from the Blind Soccer VR Training system, the improvement of shooting performance and receiving performance is analyzed separately.

Due to the data of shooting and receiving is separated from the data set, the distribution of each set of data is influenced. Therefore, in order to verify whether the shooting and receiving data of control group and variable group conformed to a normal distribution and according to this result to decide which statistical method to use to analyze the data, Shapiro-Wilk test was conducted for each of the four sets of data.

The results of Shapiro-Wilk test showed that the shooting data of control group ($W = 0.961$, $p = 0.824$) and the receiving data of variable group ($W = 0.851$, $p = 0.097$) did not significantly deviate from a normal distribution, with p values exceeding the standard threshold of 0.05; but the shooting data of variable group ($W = 0.800$, $p = 0.028$) and the receiving data of control group ($W = 0.774$, $p = 0.015$) showed significant deviation from normal distribution. This result shows that the shooting data of control group and the receiving data of variable group can use parametric tests, while the shooting data of variable group and the receiving data of control group use non-parametric tests will be more suitable. However, to maintain methodology consistence and robustness, a non-parametric method is adopted to all data.

Considering there are two groups (control group and variable group) of samples and sample size is small (8 participants for each group), the Mann-Whitney U test is adopted. This non-parametric test is appropriate for evaluating differences between two groups of independent samples without assuming normality.

After running the Mann-Whitney U test, the results as follows:

Table 4.2: Mann-Whitney U Test Results for Skill Improvement

Metric	**Shoot**	**Receive**
U value	30.0	1.0
p value	0.874	0.00128
Effect size (r)	0.062	0.969
Significance	Not significant	Significant ($p < 0.01$)

U value is the statistic of Mann-Whitney test, a smaller U value indicates a greater difference between two groups in the ranking.

P value indicates the significance of the difference. In general, if p value is smaller than 0.05, it will be considered that the difference is statistically significant.

R value quantifies the strength of the difference between two groups. A higher value of r indicates a stronger tendency for one group's scores to exceed those of the other.

From table 4.2, the results show there is no significant difference in improvement of shooting between control group and variable group (U = 30.0, p = 0.874, r = 0.062), which mean the final prototype did not lead to a statistically measurable improvement on participants' shooting performance. However, the receiving performance shows a significant difference between control group and variable group (U = 1.0, p = 0.00128, r = 0.969), which means that the system improved participants' ability to locate the spatial location of moving sound sources and to move without vision.

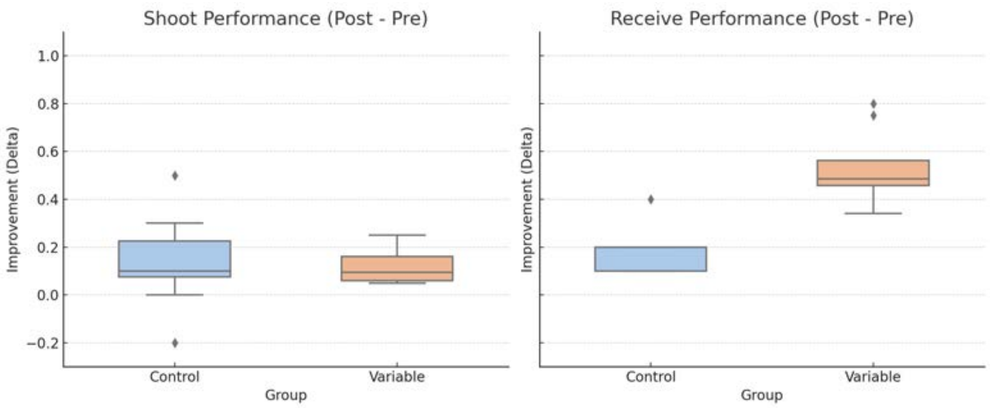

Figure 4.12: shooting and receiving performance

Figure 4.12 is created to show the results of the Mann-Whitney U test more clearly. In the figure 4.12, the medians of the two groups in shooting are similar and the distributions are highly overlapped, showing that this prototype does not provide significant improvement for participants in shooting performance. However, the median of receiving of variable group is significantly higher than the control group, and the distribution of the data was on the upper side of the range, which shows that the system can help users to improve their ability to locate the moving sound source as well as to move without vision.

4.5.3 Relationship between initial performance and improvement

To analyze the relationship between participants' initial performance reflected in pre-test and improvement by training with the Blind Soccer VR Training system, a scatter plot was generated with metrics collected in physical tasks.

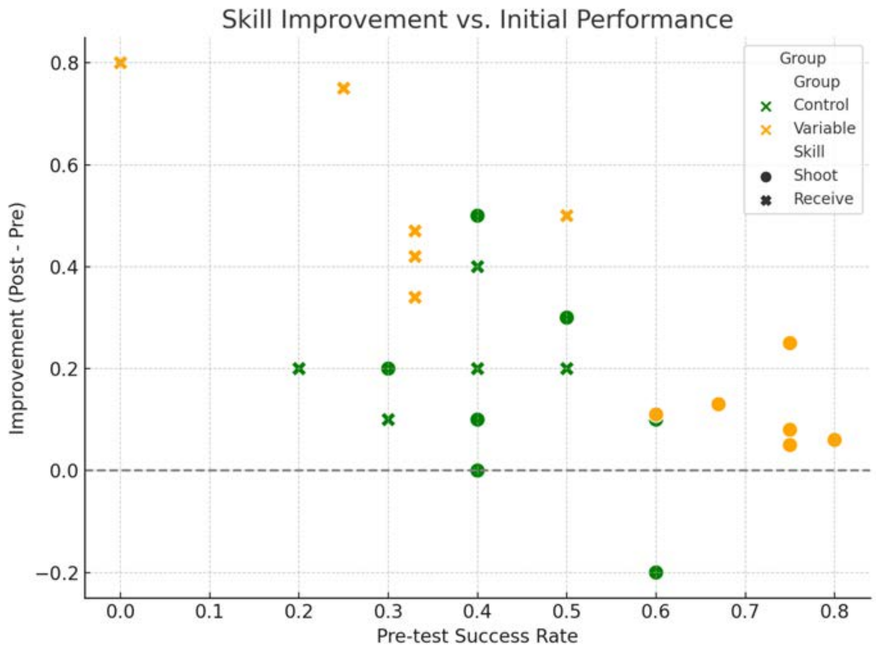

Figure 4.13: relationship between improvement and initial performance

In the figure 4.13, the relationship between initial success rate of each participant (horizon axis) and improvement (vertical axis) is shown. Markers (points and crosses) stand for different skills. Points stands for shooting, while crosses stand for receiving. Green marks shows the data from control group and orange marks shows the data from variable group.

Overall, orange markers (participants in variable group) distribute higher than green markers (participants in control group) along the vertical axis, indicating that participants in variable group gained greater improvement than those in control group. In contrast, several participants in control group show minimal or even negative improvement.

Notably, there is an inverse relationship in the data from variable group. Improvements of participants with lower initial performance (on the left part of the scatter plot) are basically higher than those with higher initial performance (on the right part of the scatter plot). This inverse relationship shows that this system is more effective in helping users who are not good at shooting or receiving football with wearing eyemasks.

4.5.4 Rating-Based Analysis of User Perceptions

In addition to quantitative evaluation, qualitative feedback was also collected from participants to evaluate whether the system can help users improve understanding of blind soccer sport and improve confidence in moving without vision and whether this system can be an alternative option for people who want to experience blind soccer but do not have conditions.

To assess participants' subjective perceptions of the system, a post-questionnaire was conducted using a set of 7 Likert-style statements. Each item was rated on a 10-point scale (1 = strongly disagree, 10 = strongly agree), enabling the collection of quantitative attitudinal data suitable for descriptive and comparative analysis.

Table 4.3: Descriptive statistics of post-questionnaire responses

Question number	Mean	SD	SE
Q1	7.62	1.85	0.653
Q2	7.88	1.73	0.611
Q3	7.38	1.92	0.680
Q4	8.25	1.67	0.590
Q5	8.38	1.19	0.420
Q6	9.12	0.83	0.295
Q7	8.50	2.00	0.707

Question reference:

- **Q1**: This system helped me better understand blind soccer.
- **Q2**: I feel more confident in playing blind soccer after using the system.
- **Q3**: I feel more confident in moving without visual input after using the system.
- **Q4**: The system provides an immersive experience.
- **Q5**: This system is helpful for beginners to learn blind soccer.
- **Q6**: This system can be an alternative option for people who want to experience blind soccer but do not have condition.

- **Q7**: I am more willing to help visually impaired people in daily life after using this system.

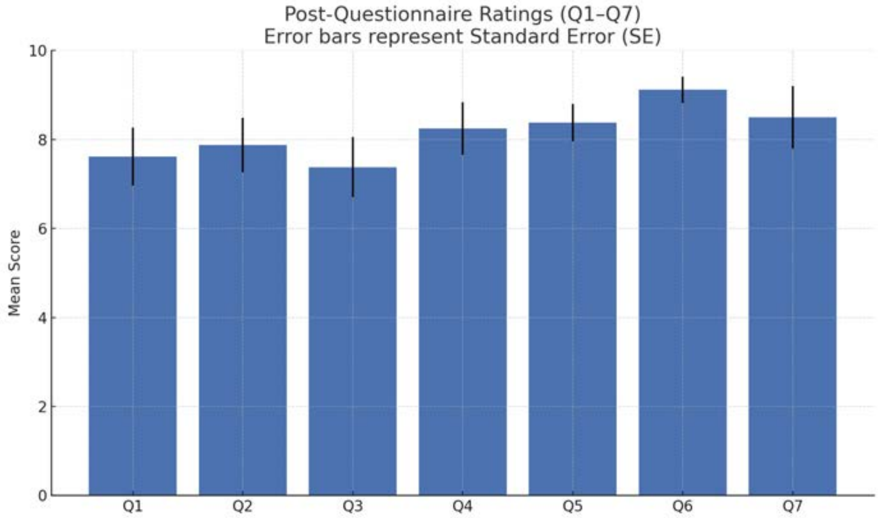

Figure 4.14: Visualization of post questionnaire ratings

The results of the descriptive statistics and visualization analysis of the scoring outcomes are presented in table 4.3 and figure 4.14 as shown.

The mean value shows generally positive user feedback. Specifically, Q6 "This system can be an alternative to traditional training." received the highest mean score (Mean = 9.12) and the smallest standard error (SE = 0.295), suggesting that participants agree that Blind Soccer VR Training system can be an alternative option to experience blind soccer for people who do not have the conditions. Q5 "This system is helpful for beginners to learn blind soccer." and Q7 "I am more willing to help visually impaired people in daily life after using this system." also received high mean values of 8.38 and 8.50.

Q5 is consistent with the data shown in figure 4.13, which reflects this VR training system is more helpful to beginners.

However, although Q7 has a high mean value, the SE of Q7 is also high (SE = 0.707), indicating that there are some disagreement among participants.

4.6. Summary

This validation process was designed not merely to test the usability of the system, but to confirm its effectiveness in simulating authentic blind soccer training tasks for beginners, while exploring how non-visual interaction, particularly through spatial sound and haptic feedback, can be meaningfully experienced in VR.

The study began with field observations and interviews at professional blind soccer training facilities, where both experienced athletes and first-time learners were observed. These insights directly informed the system interaction design, which focuses on the core beginner challenges such as spatial orientation, directional listening, and overcoming fear of movement in fully non-visual environments.

To ensure fidelity of training logic, early prototypes were tested by blind professional soccer athletes from JBFA, whose feedback helped validate that the system's interactions were aligned with real training practices. Subsequent iterations were tested by novice users at the KMD Forum, where random participants with no previous exposure to blind soccer were able to complete the tasks and provide feedback on interaction clarity. Their participation confirmed that the system design was understandable and impactful even for first-time users, supporting the project's dual aim of training and public education.

Additional tests with Australian professional players and international participants from different cultural and professional backgrounds further demonstrated that the core interaction model of the system could be understood and used in varying sensory, linguistic, and cultural contexts.

Finally, a pre- / post-test study with various participants revealed measurable gains in self-reported confidence, spatial perception, and understanding of blind soccer. The improvements, supported by quantitative analysis and visualized through box plots, highlight the effectiveness of the system in enhancing basic perceptual skills through brief and repeatable VR sessions.

In terms of all data, a comparison of shoot and receive success rates before and after training, it is found that the total success rate improvement of the participants in the variable group is significantly more than of the control group. Welch t-test confirmed that the difference was statistically significant, indicating that the improvement was not merely the result of natural improvement through repetition, but was positively influenced by the VR training system.

Further analyzation of shooting and receiving shows that this prototype has stronger positive influence in receiving than shooting. In addition, according to analyzation to figure 4.13, found that this system is more effective in helping users who's initial performance is not particularly good.

In addition, in the rating based analysis of user perceptions, the overall feedback is positive. Q6 about whether this VR training system can serve as an alternative option received the highest average score and lowest standard error, suggesting a consistent agreement of the system's practicality.

In summary, the VR system not only improved users' fundamental performance in basic blind soccer training tasks but also enhanced their confidence in non-visual interaction. The combination of objective results and subjective feedback confirms the system's potential as an alternative option for people who want to experience blind soccer but do not have conditions.

Chapter 5
Conclusion

This study presented a VR-based training system designed to support beginners to experience blind soccer through immersive, non-visual interaction. Using spatialized audio and foot-based haptic feedback, the system enables users to perform fundamental training such as audio source locating, passing and catching the ball without relying on vision. The training environment simulates real-world blind soccer conditions while maintaining a safe and structured format suitable for first-time players.

Through a multistage validation process, including field observations, professional athlete feedback, public user testing, and structured pre/post evaluation, the system was demonstrated to be both usable and effective. Participants from diverse backgrounds showed measurable improvements in spatial awareness, auditory perception, and confidence in performing non-visual tasks. Even users without prior exposure to blind soccer were able to understand the core mechanics and complete the training with meaningful feedback.

According to analyzation of the data, this system can be used as an alternative option for people who want to experience blind soccer but do not have a team, the right ball or coach to improve understanding of blind soccer and improve confidence in basic skills.

5.1. Limitation

There are still several limitations in this research.

The sample size of this study is relatively small, and the individual differences of participants may have some influence on the results of data analysis. During the testing process, it was found that some of the participants possessed a strong ability to listen and identify the location of audio source position due to innate factors or received sports training and vocal practice, and adapted faster to blind soccer as beginners. Fortunately, such cases were only isolated in this user test and did not significantly interfere with the overall results.

The sample capacity of this study is relatively small, and the individual differences of users may have some influence on the results of data analysis. During the testing process, it was found that some of the participants possessed a strong ability to hear and recognize sounds due to congenital factors or sports training and vocal practice, and adapted faster in the initial contact with blind soccer. Fortunately, however, such cases were only isolated in this user test and did not significantly interfere with the overall results.

Secondly, the limitation is the hardware. Since the speakers of the VR headset are located on the left and right sides, it is easier for users to recognize left and right movements of the sound source, while the judgment of front and back movements is relatively weak. In addition, the bHaptic foot devices, which provide vibration feedback, only have vibrators in the left, middle, and right positions, making it difficult to provide differentiated vibration feedback effects according to different vibration feedback scenarios. Meanwhile, these vibrators are distributed on the dorsum of foot, which differs from the tactile feedback felt by the foot when playing with real soccer.

5.2. Future work

Future work directions include developing more interactive content to enable users to simulate actions that are difficult or risky to achieve in real training in a safe environment, and designing related fun mini-games. For example, completing as many shooting tasks as possible within a limited time, or conducting shooting training with ball speeds within a specific range. In addition, team training systems can be developed that can accommodate more people.

In addition, kick detection algorithms with higher computational efficiency and lower misjudgment rates can be further developed, and more easily deployable and portable foot tracking systems (e.g., machine vision based tracking system) can be explored.

On the other hand, special hardware devices can be designed and developed for blind soccer training, so that visually impaired people can wear the devices and use the virtual training system independently, accessibly and safely.

5.3. What others can learn from this research

Through this research, readers can gain insights into the design of non-visual training systems, understand how to build effective VR interaction systems with audio and vibration feedback as the core interaction without visual information, and gather some inspiration in the user experience design methods in the context of sensory substitution. In addition, this research also helps participants and readers deepen their understanding of the cognitive patterns and perception of the surrounding environment of visually impaired people, therefore they can enhance their sense of empathy and provide more humanized care and support in their daily lives.

Ultimately, this research aims to contribute not only to the development of alternative option for people who want to experience blind soccer training but do not have conditions, but also to the broader goal of designing accessible VR systems that center non-visual experience as a primary mode of interaction.

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Appendices

A. pre questionnaire

User number: ____

Gender: Famale/Male/Other， Age: _______， Score:________

[1 is most negative, 10 is most positive]

How well do you understand blind soccer?

1 2 3 4 5 6 7 8 9 10

Do you have regular contact with visually impaired people in your life?

1 2 3 4 5 6 7 8 9 10

Have you ever used sound to determine spatial direction?

1 2 3 4 5 6 7 8 9 10

Have you used vibration-based cues for interaction?

1 2 3 4 5 6 7 8 9 10

How would you rate your ability to interpret vibration cues?

1 2 3 4 5 6 7 8 9 10

Have you ever used a fully non-visual interface?

1 2 3 4 5 6 7 8 9 10

Do you feel confident participating in blind soccer training?

1 2 3 4 5 6 7 8 9 10

How confident are you in completing tasks without visual input?

1 2 3 4 5 6 7 8 9 10

Are you familiar with VR devices?

1 2 3 4 5 6 7 8 9 10

B. post questionnaire

User number: ____, Score:_____

[1 is strong disagree, 10 is strong agree]

This system helped me better understand blind soccer.

1 2 3 4 5 6 7 8 9 10

I feel more confident in playing blind soccer after using the system.

1 2 3 4 5 6 7 8 9 10

I feel more confident in moving without visual input after using the system.

1 2 3 4 5 6 7 8 9 10

The system provides an immersive experience.

1 2 3 4 5 6 7 8 9 10

This system is helpful for beginners to learn blind soccer.

1 2 3 4 5 6 7 8 9 10

This system can be an alternative option for people who want to experience blind soccer but do not have condition.

1 2 3 4 5 6 7 8 9 10

I am more willing to help visually impaired people in daily life after using this system.

1 2 3 4 5 6 7 8 9 10