Exploring the Physical and Virtual Audiences in Multiverse for Seamless XR Performance

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Abstract

VR concerts gained popularity during the COVID-19 pandemic, providing a novel experience that allowed audiences to transcend physical limitations and remotely enjoy live performances. In the post-pandemic, while live concerts gradually moved back onsite form, those virtual concert features were still appreciated. We introduce an XR performance system that integrates onsite audiences and online performers to create a seamless XR performance experience across spatial boundaries. The system uses sensors to digitize venue signals and real-time data from online performers' instruments, integrating both into a virtual world. The combined data is then displayed as visuals on onsite screens. In this work, we present several interactive features for audience engagement, creating a shared experience that bridges both the physical and virtual worlds. We focus on these interaction designs and evaluate them to explore the system's potential. It aims to propose design considerations and future directions for this interactive and innovative experience.

CCS Concepts

• **Human-centered computing → Interaction design**.

Keywords

Multiverse Interaction, Music Visualization, Extended Reality, Live Performance, Audio-Visual

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1 Introduction

During the COVID-19 pandemic, VR concerts attracted attention for their characteristic of overcoming spatial limitations, allowing audiences to remotely enjoy live performances. This has driven the development of hybrid performances that combine onsite and online formats. Lin et al.[8] studied audience interaction in XR performances, comparing presence, enjoyment, engagement, and immersion between VR-HMD and phone/tablet users. The study found that VR-HMD users felt less immersed and more isolated, while interaction designs received positive feedback. Switching realities caused audiences to lose presence, and some felt isolated with VR headsets. Therefore, this paper introduces a seamless XR performance system that integrates onsite audiences and online performers with hybrid multiverse interactions. By utilizing various sensors, we capture signals from the venue and digitalize all onsite elements, transforming them into a virtual world. The visual content is projected onto screens for the audience. Our goal is to break spatial boundaries and create an immersive XR performance experience that bridges physical and virtuality. This system aims to enhance the hybrid experience by fostering a sense of co-presence and interaction between onsite audiences and online performers. In this work, we introduce several interaction designs to foster a sense of presence and enhance the audience's hybrid experience. In our study, we evaluated those designs and analyzed the proposed

XR performance system. Based on the result, we compile the design considerations for XR performance and propose design guidelines for future XR performance-related designs.

2 RELATED WORKS

In the realm of concert interaction, innovative approaches are emerging to enhance audience engagement through hybrid interaction models that seamlessly integrate XR performances. By using sensors, the signal from the venue is digitized to create a virtual version. This study discusses music visualization, audio-visual, and real-time perception. Additionally, it explores research related to VR concerts, considering technological advancements and the evolution of live performances in time and space.

2.1 Music Visualization, Audio-Visual and Real-Time Perception

Research shows that visual imagery enhances the music listening experience and plays a key role in evoking emotions[7]. However, the specifics of its content, purpose, and occurrence remain unclear. Previous works have shown that music visualization not only helps audiences understand performances better[4] but also enhances their immersion[10]. The interplay between music and visuals captivates audiences, and achieving the right audio-visual harmony is a pivotal key for a successful live concert. Performers often provide pre-recorded audio files to Visual Jockeys (VJs), who create visuals based on the music's structure, timing, and beats. This separates audio and visuals, with most performances being pre-arranged and lacking real-time interaction. Bucksbarg[3] emphasized that live media performances balance control and randomness, requiring spontaneity and unpredictability. Bown et al.[2] found that audiences judge "real-time" based on elements like improvisation, rhythm errors, and performers' actions, such as off-beat music, uneven rhythms, or pitch errors. These "mistakes" signal a live performance rather than a pre-recorded one. Capturing this "real-time perception" requires and considers the dynamics and real-time nature of live performances, innovative systems to enhance interactivity and real-time music visualizations. Therefore, combining audio and visual elements is key to enhancing the music experience, triggering emotional responses, and creating a "real-time" feel. While traditional methods for visualizing pre-recorded audio have worked, live performances require more advanced interaction solutions to address their dynamic and unpredictable nature.

2.2 XR Concert and Virtual Co-presence

Previous research has focused on improving audience engagement and interactivity to increase immersion in VR concerts. For example, the LiVRation[6] allows users to experience live recordings from a free perspective with customizable sound control. Actualities[9], creating an immersive experience by capturing live signals and transforming them into a virtual scene. DualStage[11], a real-time emotional visualization system that synchronizes the performer's actions, audience interactions, and music to enhance the emotional connection between live and virtual audiences. Lin et al.[8] proposed a live XR performance system that combines onsite and online concerts, with visuals projected and live-streamed for interactive audience engagement across multiple devices. Horie et al.[5] proposed a virtual concert system that dynamically generates visual effects based on users' brainwaves or heartbeats. These projects gave the audience more autonomy, even making them a part of the performance. Meanwhile, Beacco et al.[1] considered "presence" a key factor in VR concert experiences, aiming to create the illusion of actual participation in a live concert. Yakura et al.[13] explored computational methods to enhance co-presence in VR concerts by displaying virtual audience avatar movements. Yan et al.[14] presented a VR performance system that integrates social interactions, allowing participants to easily interact with the features, improving social awareness and immersion. However, in these studies, the use of VR-HMD successfully enhanced engagement and interactivity, audiences experienced higher immersion, it was still challenging to maintain co-presence, and some users felt isolated after using VR-HMD[8]. This study explores ways to enhance engagement and improve co-presence through sensor technology and interaction mechanisms.

In addition to fully virtual concerts, many performances incorporate XR technology into live shows. In Asia, SM Entertainment in South Korea created an online concert platform called Beyond LIVE, combining artist performances, augmented reality technology, and real-time 3D visuals to provide a rich visual experience. In 2019, the band Miro Shot hosted an XR concert, where viewers wore VR headsets and experienced a multisensory immersive environment with effects like dry ice, scents, and fans. Zappi et al.[15] explored the technical and conceptual challenges involved in immersive virtual musical instrument (IVMI) performances on stage and proposed recommendations for future immersive performance design and implementation. The intersection of music and XR has grown significantly, enabling performers and audiences to interact with virtual objects, agents, and environments in musical ways[12]. These applications of XR technologies in concerts enhance audiovisual experiences and immersion. However, it is still mainly limited to experiences within a virtual or a physical space. Our goal is to integrate onsite audiences and online performers into the virtual world using sensors, providing a hybrid multiverse interaction experience that allows audiences to exist simultaneously in both the physical and virtual, creating a hybrid immersive XR performance.

3 Design Considerations for XR Performances

In the dynamic world of live performances, the nuances of field deployment are critical. From understanding the needs of stakeholders to addressing the challenges posed by different venues and audience setups, traditional practices offer valuable design insights. As we move toward hybrid models, grounding our approach in these foundational practices is essential. Therefore, we begin by exploring the design considerations of onsite performances to establish a strong foundation for evolving hybrid performance models. To better understand the challenges of hosting live performances, we organized four events: a technical showcase with 60 attendees, a music concert with 2,000 attendees, and two opening ceremonies attended by approximately 100 and 300 people. We invited band guitarists to use our XR performance system in these events and gathered their feedback. In addition, we conducted exploratory audience research and expert interviews to enrich our understanding of the study. Finally, we gathered key experiences and distilled the following design considerations.

3.1 Pre-Show Preparations for Live Performances

Organizing live performances involves more than just the performance itself; it requires careful planning of various factors, from the event's objectives to venue setup. The event type determines its priorities, for example technical showcases focus on innovation, while concerts prioritize atmosphere and music. Each type requires unique content and arrangements. Stakeholders may also have specific needs, such as increasing brand visibility or adjusting performance content. These complexities must be addressed during planning. Venue factors like audience capacity, seating density, and stage distance impact the experience. Collaborating with technical teams and stakeholders is essential, and hybrid systems for live performances must be flexible to meet diverse needs. We strive to make the equipment intuitive and easy to use with minimal training. Additionally, we focus on balancing control to ensure audiences have a comfortable and enjoyable viewing experience.

3.2 Enhancing Live Performances

Integrating technology into live performances enhances audience engagement by fostering interaction and creating unique experiences. Audio-visual elements add a dynamic, ever-changing layer to performances. Their unpredictability and responsiveness not only increase audience involvement but also improve performance authenticity, generating visual effects that resonate with live elements in real-time. This fusion of art and technology provides a distinctive experience for both performers and audiences. However, successful integration requires careful planning, with attention to capturing live activities and subtle visualization details. To ensure smooth interaction, devices and sensors must integrate seamlessly with user-friendly interfaces, adapting to different venues and contexts. Meanwhile, experts suggest that sensors should be installed with minimal impact to avoid interfering with performers or altering the instrument. This ensures a natural and realistic virtual transformation in which the performance is accurately represented in its virtual version.

3.3 Engaging in Live Performances

Live performances shine not only through their content but also through the emotional connection between performers and audiences. As performers express their art and emotions, audiences respond with feedback, from applause to spontaneous participation, like singing along. While traditionally passive, this emotional exchange boosts audience engagement. Many performance styles strengthen the bond with actions like rhythmic clapping or encouraging audience singing by passing the microphone. Transforming audiences from observers to active participants makes them integral to the performance, enhancing their experience. To further enhance audience engagement while maintaining co-presence, It is essential to consider the interactions between the audience and other participants. Allowing audiences to provide real-time feedback can also strengthen their connection with performers, creating an XR performance experience that seamlessly blends virtual and physical.

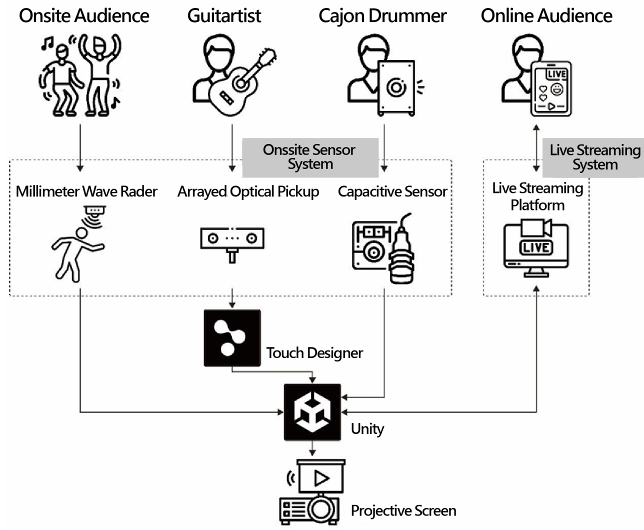

Figure 1: System architecture diagram.

4 Design and Implementation

Our research highlights the need for flexible, seamless XR performance systems that accommodate diverse stakeholders, content, and venues while fostering emotional interaction between performers and audiences. To address this, we developed a cross-reality system combining physical and virtual environments into a "multiverse"(Fig.1). Our system integrates virtual worlds with onsite stages. At the same time, online performers and audiences are digitized to appear in the virtual space. This dual integration creates a seamless hybrid performance experience, blending physical and virtual into a multiverse. The goal of online performers is to deliver seamless performances while connecting with the audience to encourage engagement. Our system achieves this by integrating technology into the performance. For example, sensors in instruments and microphones send real-time data to a virtual reality system, which creates audiovisual generative art projected onto the real-world stage, enhancing the live experience. Engaging with onsite audiences is challenging as performers typically must turn to a screen for interaction. To address this, the system uses AR-HMD to offer an augmented window, allowing performers to view the virtual world without interrupting their performance. For onsite audiences, the system captures their movements and transforms them into virtual avatars, fostering interaction with both the virtual space and online viewers. Both onsite and online attendees can express emotions through emojis from smartphones, visualized in the virtual world, enhancing emotional exchange. This system creates a richer, more interactive experience, embedding onsite audiences into the multiverse. Our system is designed to provide onsite audiences and online performers with a seamless XR performance experience that spans physical and virtual worlds, transforming traditional shows into a cross-universe experience with diverse

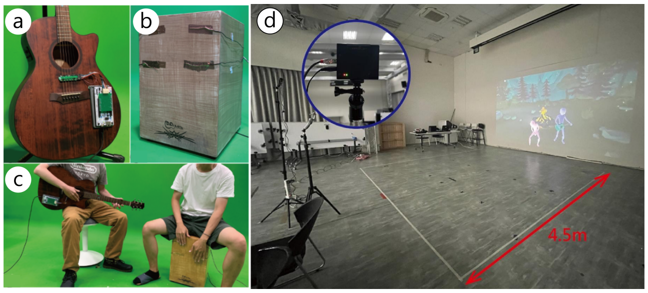

Figure 2: System Overview: (a) Optical pickup sensor fixed on the guitar; (b) Capacitive sensors positioned at the drum's striking points; (c) Performer with instrument and sensors.(d)Experimental configuration of the interaction design evaluation.

interactions. This approach allows onsite audiences and online performers to exist in the multiverse and immerse themselves in the performance.

To achieve the interaction design, we divide the system implementation into three parts: real-time music visualization, virtualization of online performers and onsite audiences, and real-time streaming and feedback for onsite audiences.

4.1 Music Visualization

To integrate audiovisual generative art into seamless XR performances, real-time audio signals from instruments are essential for generating visual effects. To ensure performer comfort, we embedded sensors in the instruments. For string instruments like guitars, we used LiCAP, an optical sensor that detects string vibrations (Fig.2a). LiCAP processes the audio signals in real time and sends the data to a computer via USB. For percussion instruments like the Cajon drum, we used capacitive touch sensors (Fig.2b). Four sensors are placed on the drum's front, aligned with the drummer's typical strike points, and connected to an Arduino Nano (Fig.2c). These signals are sent to Unity, where visual effects are created using Unity's Visual Effects Graph (VFX Graph), producing dynamic visuals like particle explosions and floral displays. This approach ensures adaptability and allows for continuous visual performances.

4.2 Virtualization of Online Performers and Onsite Audiences

To capture the relative positions of onsite audiences in the virtual world without disrupting their natural behavior, we placed two millimeter-wave radar sensors on the stage to monitor the audience. The MT5A61E01K radar, with a detection range of 15 meters and a horizontal range of 120 degrees, sends data to Unity via USB. In the virtual environment, the audience appears as virtual ghosts around a campfire, while performers are represented as virtual avatars performing their real-life actions. Despite challenges with dynamic stage lighting, the system ensures real-time transformation of the performers image and maintains consistent virtual representations. Audience reactions are captured by microphones and streamed into the virtual world.

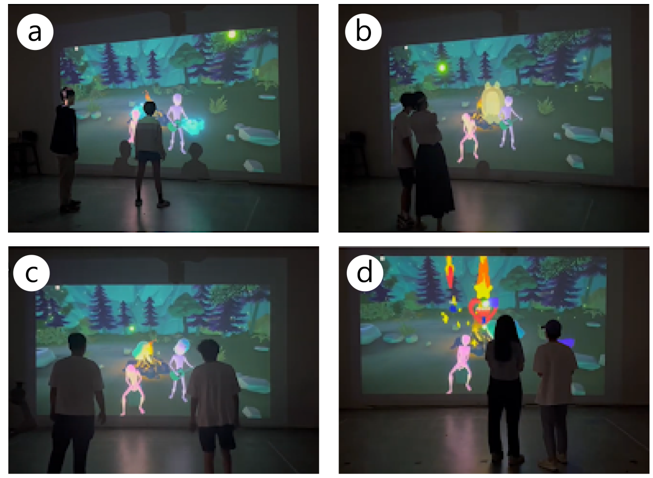

Figure 3: Interaction design: (a)Appear/Disappear, (b)Merge and Transform, (c)Ignite the Campfire, (d)Emoji.

4.3 Live Streaming and Feedback

While 3D virtual spaces with interactive interfaces enhance immersion, they require high device specs and app installations, which can be challenging in real-world setups. To overcome this, we offer a 360-degree virtual environment accessible through device browsers. Our system uses Audience SDK for 360-degree live streaming, allowing viewers to watch the performance on smartphones, laptops, or VR headsets. Additionally, the Emoji interaction generate an avatar in the virtual world, allowing audiences to send emoji and share feedback, enhancing engagement by influencing the performance's visual atmosphere.

5 Interaction Design and its Evaluation

Building on the proposed system, we introduce interaction design elements that enhance the audience's sense of presence and co-presence during live performances. Additionally, we conduct a user study to analyze audience behavior, gather feedback, and explore their interactions with the system, providing valuable insights for future interaction design improvements. In this study, the millimeter-wave radar detects onsite audience movement, turning them into virtual avatars displayed in a Unity-created virtual scene projected onto a semi-immersive screen. Background sounds include acoustic guitar and cajon drum melodies, along with a campfire burning. A 4.5m x 4.5m interactive area is set 1 meter from the screen (Fig.2d). This experiment offers four interaction modes: (1)***Appear/Disappear(AD)*** (Fig.3a) makes participants focus on their virtual avatars. When detected by the sensors, a virtual avatar appears with particle effects; when not detected, a disappearing particle effect is triggered. (2) ***Merge and Transform(MT)*** (Fig.3b) encourages participants to interact with each other. When the sensors detect participants getting close, their avatars merge, creating a larger new virtual avatar. (3) ***Ignite the Campfire(IC)*** (Fig.3c) aims to boost participants interact with objects in the virtual environment. When the sensors detect their avatar approaching an object (e.g., the campfire), the object is affected and changes (e.g., the campfire is ignited). (4) ***Emojis(EM)*** (Fig.3d) allows participants to give feedback on the virtual musicians and their performance. Participants can enter the live-streaming platform and click emojis to provide feedback on the performance. To further understand the interaction effects of the system, we propose the following research questions:

- **RQ1:** How do different interactions of the system influence participants' sense of connection with their avatars, other participants, and the virtual environment?
- **RQ2:** How do different interaction mechanisms affect participants' sense of embodiment with their avatars?
- **RQ3:** What types of interaction can enhance more Presence and Involvement when audiences engage with the virtual environment and other participants?
- **RQ4:** How do the system's interaction affect the Physical/Virtual Co-presence and connection among audiences?

In this interaction design evaluation, 32 participants (ages 18–31, average 24.3, SD 3.29; 20 females, 12 males) were recruited. Of them, 26 (81.3%) had VR experience, 25 (78.1%) had VR projection experience, and 25 (78.1%) were from an interaction design program. Before the experiment, we explained the content and process to the participants. Participants experienced four interaction designs in pairs. We randomized the order using a Latin square design. Before each experience, researchers explained the goals and interaction methods, and participants' behaviors were recorded for analysis. After each experience, participants completed a 7-point Likert scale questionnaire, customized from the Igroup Presence Questionnaire. Once all experiences and questionnaires were completed, we conducted semi-structured interviews to evaluate the designs.

6 Results and Discussion

We used Mauchly's Test of Sphericity to verify whether the data met repeated measures ANOVA (RM-ANOVA) assumptions. After confirmation, we conducted RM-ANOVA to analyze the effects of the four interactions, evaluating differences in participants' behaviors and experiences across various interaction scenarios.

6.1 Connection

In the interaction design evaluation, based on **RQ1**, we assessed which elements the participants felt the strongest and weakest connection to determine whether the designs met our goals. In the AD interaction, 29 participants (90.6%) felt the strongest connection to their avatar. We found that creating dynamic visual effects for "appear" and "disappear" helped direct participants' attention to their avatars. In the MT interaction, 14 participants felt the strongest connection to another participant's avatar, and 8 felt the strongest connection to the actual participant. In the IC interaction, 19 participants (59.3%) felt the strongest connection to the virtual environment. Participants interacted by manipulating their avatars and triggering visual effects. In the EM interaction, 10 participants (31.2%) felt the strongest connection to their phone. Some felt the strongest connections to the virtual performer, scene, or music. Four participants (P4, P15, P18, P32) selected "Other" and wrote "Emojis," while one (P26) wrote "Connection with another identity generated by the audience system."

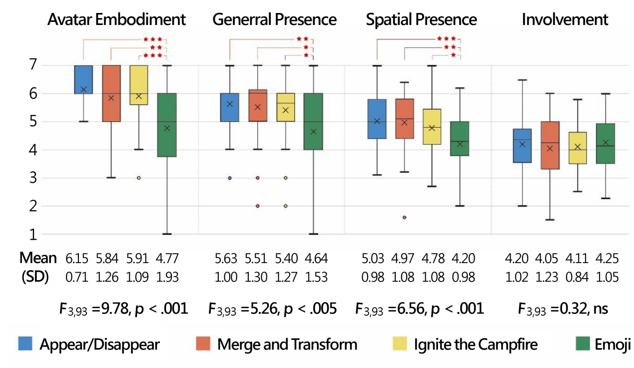

Figure 4: Result of the Avatar Embodiment, IPQ questionnaire.

6.2 Avatar Embodiment

According to the RM-ANOVA and Tukey post-hoc tests (Fig.4), Interaction AD, MT and IC significantly outperformed EM in avatar embodiment. We examined how different interactions influence participants' sense of control and digital identity (**RQ2**). Most participants reported that during the interaction EM, a secondary avatar was generated as the emoji sender when they entered the platform via the live streaming system, leading to confusion about digital identity in the virtual environment. In the MT interaction, some participants (P3, P4) mentioned that the visual changes of the avatars during merging and splitting with another participant were not precise and responsive enough, affecting their perception of control. Additionally, detection failures due to occlusion or blind spots impacted their sense of control over the avatars.

6.3 Presence and Involvement

For **RQ3**, we examined how different interaction designs influence presence and involvement. In the presence result, we used the IPQ questionnaire and deliberately omitted the category "realism." Our goal was to create a seamless XR performance experience that blends real and virtual elements rather than replicating the real world. In terms of General Presence and Spatial Presence, EM was significantly lower than the other three interaction designs (Fig.4). The average score for the "I feel like I'm just perceiving an image" item in "spatial presence" was only 3.9, and for "I feel like I'm moving in the virtual space, rather than operating something from the outside," it was 3.5. These results indicate that interacting with emojis enhanced participants' sense of external control, making them feel more like receiving digital images in the real world rather than being immersed in a virtual world during performance. Regarding Involvement, the average scores for all four interaction designs were around 4, showing no significant differences(Fig.4). This is because while participants experienced the virtual world, they still focused considerable attention on the real world. The lower engagement scores were not due to the lack of appeal in the virtual world. In fact, the scores for the item "I was fully immersed in the virtual world" were high for all four interaction designs: 5.0, 5.4, 4.9, and 5.1. User interviews revealed that the lower engagement scores were mainly due to participants' attention to the real space.

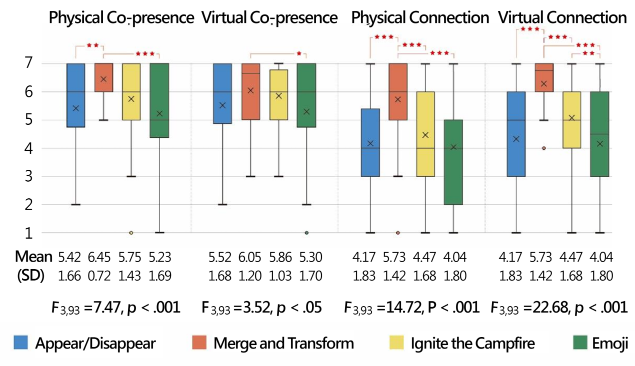

Figure 5: Result of the Result of the Physical/Virtual Co-presence and Connection.

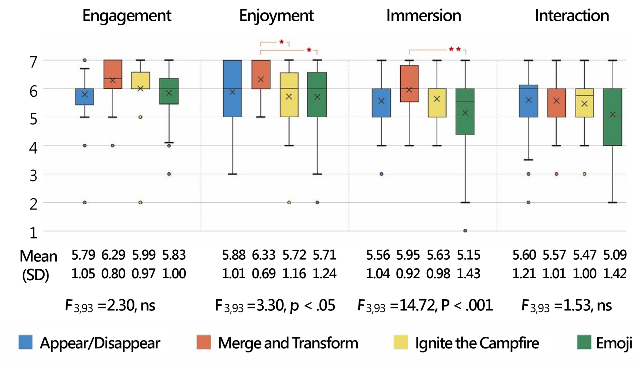

Figure 6: Result of the Engagement, Enjoyment, Immersion, and Interaction.

This focus was not on the "real" physical space but more on the activity boundaries and distance from other participants during the experience.

6.4 Physical/Virtual Co-presence and Connection

In the IPQ questionnaire (**RQ4**), Presence refers to participants feeling their "self" in the virtual world. Meanwhile, our custom questionnaire investigates co-presence of physical and virtual, focusing on whether participants experience a shared presence with another participant in the physical/virtual space. MT scored the highest for Physical Co-Presence and Virtual Co-Presence (Fig.5). It significantly outperformed AD and EM in physical co-presence, and also exceeded EM in virtual co-presence. In MT, participants had to be physically close to each other to create visual effects in the virtual scene, merging two avatars into a larger one. This design enhanced the sense of Co-Presence between the physical and virtual. AD aimed to help participants focus on the connection with their own avatars. During the experiment, we found that participants focused on creating or making their avatar disappear by moving in and out of the detection range or staying still, confirming their position in the virtual world. Focusing on their own avatar reduced physical and virtual connections with other participants. EM yielded similar results; in this interaction, participants focused more on their phones and the emoji effects they triggered, neglecting the other participant. We evaluated four interaction designs, common positive indicators in semi-immersive virtual reality (VR), including engagement, immersion, enjoyment, and interactivity. Most participants gave positive feedback, with average scores above 5 for all items. MT scored highest in engagement and enjoyment, exceeding 6 on average (Fig.6).

7 LIMITATIONS AND CHALLENGE

Audience research on live performance often uses observations and post-event interviews. In this study, we combined both methods but faced challenges maintaining the "consistency" of each XR performance. As mentioned earlier, the uniqueness of live performances lies in creating a momentary experience. Factors such as on-site equipment, instrument sound conditions, musician performance styles, tempo, and band member dynamics affect performance. It is not easy to replicate the same experience in each study, particularly in audience research, which can impact the audience's experience. Additionally, audience emotions during performances are progressive and cumulative, influenced by different segments of the performance. While immediate emotions and reactions are the most authentic, we could only assess them through post-performance interviews, which may introduce some distortion. Among the participants, 26 had VR experience, and 25 had a background in interaction design. Since most participants were familiar with XR technology, their feedback may not fully represent general users. So, the results mainly apply to users familiar with XR technology. Further validation is needed to determine their applicability to less experienced or first-time XR performance audiences, ensuring more representative findings.

8 CONCLUSION AND FUTURE WORK

In this paper, we introduce an XR interactive performance system designed to enable both onsite participants to experience a hybrid seamless XR performance that bridges physical and virtuality, exploring ways to integrate the virtual and real world to provide an immersive and engaging performance experience. The study showed that our system's interaction designs significantly enhanced engagement and immersion. However, the hybrid nature of the performance sometimes distracted the audience. Different interaction modes improved engagement and provided a richer, seamless XR performance experience. In the future, we will conduct more audience research for seamless XR performances and expand music visualization to include a broader range of instruments beyond guitars and cajons.

Acknowledgments

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