Breaking Human Boundaries: VR Embodiment of Self-reflection in K-pop Choreography

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K-pop dance, as a global phenomenon, elevates human creativity through its widespread social media presence, significantly increasing its popularity in Virtual Reality. This paper explores how immersive technologies can be designed to create interactive, embodied movements for dance practitioners who wish to incorporate virtual choreography into their artistic expression through interactive technology. Existing digital solutions, such as Dance Central and Just Dance, attempt to tackle these challenges with outdated 2D gamified preview graphics, lacking precise kinaesthetic knowledge, and underutilizing the potential of a 3D environment. To address these key issues, we develop a VR prototype and conduct five rounds of autobiographical studies involving self-practicing with the prototype. We collect first-person lived data, including in-depth self-reflection and video documentation of the practicing process. We discuss the advantages and limitations through third-person observation and first-person embodied experiences using thematic analysis in a reflective and critical manner. Design considerations, including the use of modified digital choreography and human intervention in VR, are provided for grounding this prototype in future studies.

CCS Concepts: • **Human-centered computing → Virtual reality**.

Additional Key Words and Phrases: design, immersive experience, virtual reality, digital performance, K-pop choreography, machine learning, first-person experience, embodied experience

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1 Introduction

1.1 Background, Context & Motivation

Dance, as an artistic form of performance, is a universal human behavior of self-expression and discovery, holding enduring significance in the field of Human-Computer Interaction (HCI) studies [1–4]. Virtual Reality (VR), as a new medium, offers opportunities for creative, interactive, and immersive experiences in movement-based activities, allowing dance practitioners to simulate experiences that perform beyond human physical limitations in a boundless space[2, 5–7]. VR also provides real-time feedback for users to develop dancing knowledge through learning experience in an engaging way [8]. Existing VR dance-related games address these problems by employing dated 2D gamified preview graphics, under-utilizing the opportunities presented by a 3D environment in VR.

K-pop, the Korean wave, or *Hallyu*, has become a global phenomenon due to its rise on social media and its significant production values on stage performances, choreography and camera work [9, 10]. Meanwhile, K-pop is a

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dance-driven performance [11], encompassing various genres such as dance-pop, pop ballads, rock, jazz, hip-pop, and electro-pop, featuring catchy rhythms [12], set choreography [13], and emphasis on synchronization [14]. This level of synchronization is crucial for achieving a visually stunning and cohesive dance performance, often reflecting the professionalism and rigorous training of K-pop idols and groups. The popular social activity, like Random Play Dance (RPD), invites K-pop fans to communicate with each other via body language, highlighting the unique kinaesthetic significance of synchronized social dancing [15]. This research project aims to address the importance of precise kinaesthetic knowledge and somatic awareness [16–19] of K-pop choreography in designing interactive artifact with first-person perspective bodily experiences and felt sense [3, 20–27]. The methods used in this study also encourages HCI practitioners to extend their artistic work into various fields involving new technology and human embodiment.

In recent years, machine learning (ML), as a subset of artificial intelligence (AI), has been widely utilised in HCI choreography [28–31]. As K-pop has a vast database of professional dance videos [32], machine learning models can efficiently extract 3D skeletal tracking from these videos. This enables the creation of virtual characters that exhibit human-like precision and adaptability. By rigging virtual choreography onto a humanoid character, these outputs can be utilized in interactive, movement-based activities [33], providing an immersive experience for dance practitioners to learn precise kinaesthetic knowledge in Virtual Reality [34–37].

From a post-modernist perspective, Haraway's "Cyborg Manifesto" [38] emphasizes the dissolution of boundaries between human and machine. In the context of VR, users can adopt various avatars [33] and engage in interactions that challenge and expand their understanding of body and movement perception. The performative nature of VR experiences aligns with Butler's notion [39] that self-identity is fluid and constructed through ongoing social interactions. Haraway and Butler's theories deepen the understanding of how VR transcends the physical world by facilitating a reconfiguration of boundaries and self-reflection. This postmodernist framework inspires HCI practitioners to consider how VR and ML can be leveraged to explore and expand the possibilities of human embodiment and artistic exploration, ultimately contributing to the development of more intuitive and interactive technological interfaces. K-pop choreography in virtual reality, characterized by its set choreography and synchronization, requires precise kinaesthetic knowledge [40] and somatic awareness to develop an effective digital artifact. Therefore, we propose these research questions.

- ***1: How can Virtual Reality (VR) be used to prototype and evaluate participants' movement-based interactive experiences?***
- ***2: What methods and processes can be developed to allow designers to identify movement limitations and provide reflective feedback to offer potential solutions for mitigating these short fallings?***

To address the research questions, we propose solutions that enable participants to experience movement-based interactions with the precision and synchronization standards of K-pop choreography. Specifically, we explore a VR prototype for dance practice through a detailed movement study of the K-pop choreography "*Maniac*" by Stray Kids, choreographed by Men of the Future (MOTF). To analyze the prototype, we use a research-through-design (RtD) approach [41], collecting five rounds of lived data using autobiographical methodologies from a first-person perspective [5, 16, 42] throughout the VR design process. Post-study self-reflection is recorded in a digital diary with self-observations of body perception [43–45] after each dance practice, including video recordings and written documentation.

The outcomes of this research project contribute novel design knowledge by prototyping immersive and interactive experiences in VR using K-pop choreography. This work discusses both advantages and potential limitations that impact the design process, along with their corresponding design considerations. Additionally, the design workflow utilizing skeletal tracking methods offers a methodological contribution to the future development of HCI choreography in VR. The thematic analysis includes first-person lived data and third-person frame-by-frame observation of each autobiographical study. We believe our findings will be valuable to HCI practitioners who aim to incorporate embodied experiences in movement-based design within VR.

2 Related Works

2.1 Somaesthetics and Kinaesthetics in HCI/VR

This research project starts with an embodied approach of a design movement-based interactive artifact [5] in Virtual Reality, which requires designers understand somaesthetic and kinaesthetic knowledge. The exploration of our design approach is positioned in a context of somaesthetics and somatic feelings [4, 16, 46, 47], kinaesthetics [48–50] and embodiment, embodied interaction [51–53], felt sense and felt experience [3, 22, 25, 54, 55].

2.1.1 Somaesthetics, Somatic Interaction

Somaesthetics is a theoretical framework introduced by Richard Shusterman (1997), who developed exemplary somatic philosophers John Dewey and Foucault's stance towards aesthetic experience. "Soma" means "body", and "esthetics" indicates the body perception. The idea of somaesthetics emphasizes the significance of physical experience in aesthetic appreciation [17–19], which provides theoretical foundations to design movement-based interaction in Virtual Reality. *Somatic* practices, developed by American philosopher, Thomas Hanna (1988), focus on the body's internal sensations, leading to a deeper understanding of how users physically and emotionally interact with technology [4]. This can improve the design of more intuitive and engaging interfaces. In contrast to natural "analog" physical sensations, reliving oneself within virtual cyberspace in a phantom pseudo-body produces false ecstasy [57], which requires designers to adopt increasing virtualization of the natural body. From a practical dancer's perspective, it is crucial to distinguish the change in roles between real-world spectators and virtual audience by using their own somaesthetic feelings and somatic practices[3, 4, 44, 58]. Theoretical frameworks about somatic practices and somaesthetics offer underpinnings to shape design practices in movement-based virtual reality project [16], often integrating kinaesthetic concepts as well.

2.1.2 Kinaesthetics

Kinaesthetics refers to the study of bodily movements, sensations, and perceptions, emphasizing the role of sensory feedback in human cognition and physical expression, initially theorized by Aristotle around 334 BC. The concept was further developed in the 1970s by the German choreographers and dancers, Hatch and Maietta [48]. Compared with other learning approaches like visual, auditory, read and write behaviors, kinaesthesis involves learning through the movements an individual performs, which strongly connects with the process of movement design in VR prototyping [48, 49]. Related with somatic ideas, Barbara Todd's approach emphasizes the integration of mind and body in movement practices, advocating for conscious awareness to enhance movement expression [59]. Through the development of ideokinesis, Lulu Sweigard's idea focuses on the use of imagery and mental visualization to improve movement quality and efficiency [60], influencing contemporary somatic practices. Another study also finds that a virtual avatar in VR can prompt dance practitioners to focus on and respond to their unique movement patterns [61]. Kinaesthetic framework provides practical guidelines for motion designers to develop movement-based artifacts, especially for the interplay of embodied interaction in HCI research processes [62–64].

2.1.3 Embodied Interaction, Embodied Experience and Felt Experience in HCI Studies

Sensual cognition, self-awareness and learning one's emotion through observing the body's reactions [21, 26, 54, 57] needs to be addressed in the somatic virtual design. To design a movement-based experience in virtual reality, the perspective of somatic experiencing analysis varies from first-person (I-Me) position, second-person (I-You) experience, to third-person (I-It) perspective, depending on the role of the designer or choreographer [5, 65]. To enhance interactivity, visual cues from a first-person viewpoint of an embodied humanoid avatar are processed like those from one's own body, facilitating deep engagement in the performance [66]. Felt experience refers to the embodied and subjective perception of interactions and movements within a digital environment and is closely tied to proprioception, the sense of the relative position of one's own body parts [3, 25]. In VR, accurate proprioception is essential for effective navigation and interaction. Understanding the concept of felt experience aids HCI designers in improving spatial awareness and movement precision through self-observation, which is integral to building virtual choreography in this research project.

2.2 HCI Choreography in Virtual Reality

Third wave HCI has shifted towards using the body as an instrument that encapsulates multiple human perceptions, expressions, and experiences of the world [44, 67–69]. In the HCI community, VR, as an efficient and immersive tool, presents a significant chance to reexamine the relationship between bodily movement and real experiences and to perform with it in a regulated, entertaining, and sustainable fashion [70]. Dance experience productions, such as K-pop choreography and performance, are creating novel insights and choreographic experiments that could eventually shift performance design in an entirely novel direction [50].

2.2.1 Laban Movement Analysis (LMA) & Labanotation

Integrating somatic awareness and kinaesthetic sensitivity, Laban Movement Analysis (LMA) method, developed by Rudolf Laban and his colleagues, provides a comprehensive comprehensive framework for understanding and enhancing embodied interaction and movement expression in VR environments [71]. LMA provides a comprehensive vocabulary to categorize qualitative aspects of human movement, capturing both individual and social variations in movement expression [72]. It encompasses four key domains: "Effort", "Shape", "Body", and "Space" [71, 73]. These domains facilitate the recognition of bodily changes and offer a structured approach to understanding movement dynamics. LMA is proven to be applicable and efficient as a framework for observing and analyzing virtual dance for virtual reality dance self-learning [8, 32, 74, 75]. Extensive utilization of motion capture and analysis technologies has laid the groundwork for the critical examination of movement features in dance, including the attempts of capturing and analyzing the Laban Movement qualities with new media [76].

Labanotation (Fig.1) offers the visual perspective on the movements of the performers, or players as well [77], which provides visual cues for participants to preview the choreographed movements in virtual reality. Compared to other notation systems like Benesh Movement Notation (BMN) [78], Labanotation is more versatile in diverse dance contexts [79]. Taking examples from VR dance games, *Dance Central* (Fig.2) and *Just Dance* (Fig.3) both contain visual cues of dance movements in small scales. However, the notation system used in existing VR games remains two-dimensional effect and needs to be improved to 3D paths to guide players' movements accurately.

Therefore, LMA and Labanotation can be employed to develop and assess the interface for K-pop choreography in designing a VR dance artifact. By analyzing the user's movements through the lens of LMA, the system can provide real-time feedback on aspects like effort and spatial utilization, helping the dancers improve their technique and expressiveness. Moreover, the system can adjust the virtual environment according to the user's movement qualities, enhancing the immersion and responsiveness of the kinaesthetic training experience.

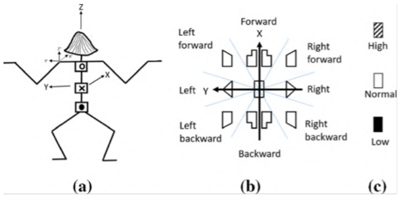

Fig. 1. Labonotation [75]

Fig. 2. Dance Central Notation System [80]

Fig. 3. Just Dance Notation System [81]

2.2.2 HCI Choreography (K-pop Focus)

Based on Broadwell's study [32], LMA has significant capabilities to help analyze movement for K-pop dance with a high standard of synchronization. South Korea boasts a comprehensive training system for K-pop performers, offering numerous professionally choreographed practice versions and fan-produced "covers" available online, which provide rich opportunities for designers to study movement using digital artifacts [32]. The importance of interactivity and inclusion in virtual space needs to be addressed to deliver a sense of empowerment and an innovative experience to the performers or the players. To review related artifacts in the K-pop performance field, *Dream Idols* [82] offers fans an immersive concert-grade experience using cutting-edge computing and motion capture technologies, but it lacks interactive elements. Yoon (2022) emphasizes that participant satisfaction is crucial in the early stages of designing artifacts for immersive and interactive dance experiences in VR. High participant satisfaction positively impacts continuous immersive attention, which enhances the overall experience in educational, entertainment, aesthetic, and escapist aspects.

2.2.3 Machine Learning in HCI Choreography

In the realm of HCI choreography, machine learning (ML), a subset of artificial intelligence (AI), is reshaping traditional design workflows by enabling automated tasks, accelerating the design iteration process, and enhancing creativity [28, 30, 31]. ML algorithms are designed to recognize hidden patterns, adapt behaviors based on empirical data, and predict future occurrences [84]. This unique feature of machine learning can be used to analyze and create virtual choreography in this research study. The recent advancement of machine learning-based pose detection methods has enabled the accurate identification of human body positions from K-pop video frames [32]. In the context of HCI K-pop choreography, machine learning algorithms play a crucial role in skeletal tracking and designing virtual avatars to simulate movements in VR [33].

2.3 Autobiographic Study in HCI

As a reflective research method, the autobiographical study is a useful tool to juxtapose the somatic awareness and self-evaluation at the same time in HCI choreography. This unique method in HCI involves the in-depth self-reflection of the researcher's personal experiences, and interactions with technology in the digital realm [45, 85–87], going beyond the traditional dance experience. This approach enables researchers to capture the richness of bodily sensations and movements, fostering a deeper understanding of how interactive technologies can enhance user experiences [88]. The autobiographical study provides detailed, first-person insights into embodied experiences [26, 89], facilitating a user-centered, iterative, and authentic approach to design. Aligned with Spence's emphasis on sensory and somatic dimensions [90, 91], these studies ensure VR prototypes are continuously refined based on real, lived experiences. By offering authentic and rich qualitative data, autobiographical studies contribute to creating more effective and engaging movement-based artifacts in HCI.

2.4 Virtual Reality Dance-Related Games Review

Learning from the successes and shortcomings of existing VR products enables researchers to adopt effective strategies and avoid pitfalls, ultimately enhancing the overall effectiveness and user satisfaction of their designs. These gaps often encompass aspects such as the precision of movement tracking, the quality of kinaesthetic feedback, and the level of interactivity provided to users [92]. Additionally, studying current products provides researchers with an understanding of the latest technological advancements in VR dance games, including innovations in motion capture, 3D environment rendering, and user interface design. These insights categorize popular VR dance games into two main domains: (1) rhythm exergames; (2) dance choreography games.

2.4.1 Rhythm Exergames in VR

The rhythm exergames in VR, which combine physical activity with gamification, cultivate captivating dance experiences within a virtual environment. *Beat Saber* [93] (Fig.4) is a movement-based game where players slash through blocks representing musical beats with lightsabers, providing a rhythmic workout experience rather than a professional dancing instruction. *Synth Riders* [94] (Fig. 5) is also a rhythm game where players ride the rails of a musical landscape, hitting notes and dodging obstacles, providing an energetic movement experience without structured dance choreography. *OhShape* [95] (Fig.6) enables players to match their body positions to fit through oncoming wall cutouts, combining individual dance poses with rhythm-based gameplay for an immersive and engaging workout experience. The games discussed above primarily focus on rhythm-based gameplay and immersive musical experiences, rather than on teaching or simulating actual dance routines. Neither game emphasizes learning or practicing specific dance moves, choreography, or kinaesthetic knowledge, which goes against the research objectives of this research project.

Fig. 4. Beat Saber [96]

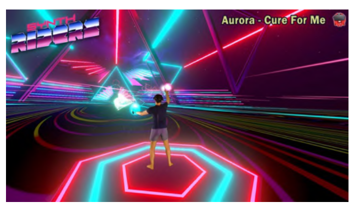

Fig. 5. Synth Rider [97]

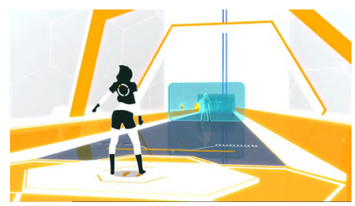

Fig. 6. OhShape [98]

2.4.2 Dance Choreography Games in VR

The *Dance Central* series and *Just Dance* series provide interactive choreography instructions and unique notation systems, which are highly applicable to dance practitioners who wish to develop kinaesthetic knowledge. *Dance Central* [80] (Fig.7) teaches players full-body dance routines paired to popular club music using a motion-sensing interface. *Dance Central* offers simplistic, repeated choreography set to club music rather than professionally choreographed movements, which fails to meet the complexity found in K-pop choreography. The *Just Dance* video game series [99] (Fig. 8) demonstrate neon-like dancers performing mirrored moves synchronized with music. The first VR prototype of Just Dance 2017 was demonstrated by Australian YouTuber Jayden Rodriguez at E3 2016 [100], but the prototype was never commercially released. Jayden's VR prototype explores strong potentials of *Just Dance* to take its success of virtual avatar and choreography design to apply in the 3D immersive space. *Just Dance*, which is not officially adapted in VR, lacks a fully immersive 3D feel due to its gameplay mechanics and visual style, which focus more on the movement of 2D avatars with highlighted outlines on screen rather than creating a fully three-dimensional environment based on the analysis of official trailer in June 2024.

These games have garnered widespread popularity worldwide and serve as a strong foundation for this research study. However, their focus predominantly centers on Western pop songs and lacks emphasis on the distinctive attributes of K-pop, such as meticulous synchronization and set choreography. This project builds upon their utilization of 3D virtual space, mirrored avatars, and innovative notation systems. Moreover, this research endeavor seeks to devise a more intuitive artifact capable of simulating movements that align with the specific demands of K-pop choreography.

Fig. 7. Dance Central VR [101]

Fig. 8. Just Dance Video Game 2023 [102]

Furthermore, it is of significant importance to HCI practitioners to effectively translate the responses of the players, thereby enhancing the subtle, invisible interactions between the player and the fictional character [103]. Empathetic relationships in digital games are facilitated within digital media settings, as users can virtually share and engage with the virtual world and its characters [104]. Both interaction and identification benefit from this dynamic, promoting endorsement and engagement that trigger players' behavioral intentions to participate in the performance [105]. From the perspective of avatar design, *Dance Central* proves to be more effective than *Just Dance*, as the interaction between the player and the virtual "coach" includes meaningful gestures, such as handshakes and celebrations. In the context of this research project, it is essential to enhance the interaction between the player and the virtual avatar in VR environments [33].

3 Research Gaps and Design Opportunities

The literature review and critique of current digital dance-related games identify research gaps and potential design opportunities. The emphasis of K-pop choreography on set and synchronized movements offers a structured framework crucial for developing precise and immersive HCI dance training systems. The current challenges in VR technologies hinder the precise translation of kinaesthetic movements using K-pop choreography into a virtual setting. While existing products, such as the *Just Dance* video game series, make efforts to address these challenges, they continue to rely on outdated 2D gamified preview graphics and fall short of fully utilizing the immersive capabilities of a 3D environment. Furthermore, *Dance Central* series lack the necessary understanding and interpretation required for the high precision demanded by its original set K-pop choreography.

The literature review reveals that traditional dance involves a complex interplay of bodily sensations and proprioceptive feedback that guide a dancer's movements. In professional physical dance training, self-reflection enables dancers to internalize feedback, refine techniques, and express individuality. Replicating these nuanced somatic experiences in a VR setting poses challenges due to current limitations in haptic feedback and sensory immersion. VR dancing requires meaningful self-reflection, incorporating tools such as real-time performance analytics, personalized feedback systems, and reflective documentation. A reflective approach is essential to simulate the tactile and kinesthetic sensations of physical dance in virtual environments. Challenges and opportunities from prior research on VR dance games were critically examined to identify the following research gaps:

1: Designing virtual K-pop dance in VR requires precise kinaesthetic knowledge to translate its visual vocabulary of set choreography into 3D virtual realm.

2: The movement-based interactive artifact lacks a reflective methodology for K-pop dance practitioners to enhance their skills with personal somatic experiences in VR.

4 Methodologies

4.1 Research Context and Research Design

The methodology in this study is under a research-through-design (RtD) structure [41] to outline the design and self-evaluation process. The diagram (Fig. 9) below demonstrate how skeletal tracking and VR prototyping process intersect with autobiographical studies, followed by thematic analysis. The previous literature review and current products critique provide a unique, but useful, research method that can be applied to explore the potential shortcomings and advantages of VR products related to HCI choreography. In the domain of HCI choreography, virtual dance constitutes a movement-based performing art in which self-expression is facilitated through somatic awareness and reflective practice [106]. The example of the K-pop boy's group "Stray Kids" choreography from their "*Maniac*" video is chosen for exploration because it includes coordinated movements with various dance techniques. Autobiographical studies throughout the VR prototyping process can provide valuable feedback and self-evaluation after each dance practice [45]. The researcher's first-person experience with lived data [21, 43] offers rapid and authentic feedback based on reflective memories and somatic sensations, which contribute valuable empirical data for thematic analysis. The primary researcher's background in K-pop training contributes to a higher level of understanding of kinaesthetics than most designers without relevant experience.

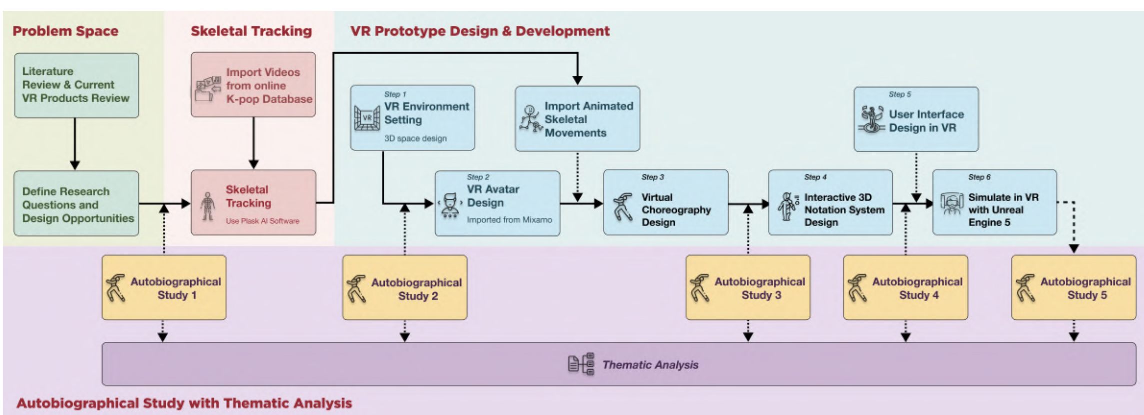

Fig. 9. Research Design

4.2 Skeletal Tracking

4.2.1 From 2D Videos to 3D Skeletal Movements using PlaskAI

A valuable tool for detecting 3D movements from 2D video footage is PlaskAI (Fig. 10), a motion capture software developed by a South Korean startup. This innovative software employs machine learning techniques to extract an avatar's movements from video content and retarget them onto a 3D virtual character. Initially, it is essential to select appropriate videos, preferably those with a clear background and distinct movement patterns. If the selected dance videos contain challenges, such as cluttered backgrounds or multiple dancers, it is advisable to segment the footage utilizing motion tracking features in Adobe Premiere Pro or other professional editing software. This pre-processing step ensures the isolation of individual movements, thereby enhancing the accuracy of motion capture.

After preparing the video, users can upload it to PlaskAI and configure relevant settings, including frame rate and tracking options, to optimize the analysis. Users can then preview the captured movements, enabling them to make necessary adjustments for improved accuracy and fidelity. This process involves skeletal tracking, which utilizes machine learning algorithms to capture and analyze the movements of humans or objects by identifying and tracking key points (joints) within their skeletal structure [34–37].

However, a current limitation of PlaskAI is its inability to simulate hand gestures in the character animations. Despite this restriction, it has minimal impact on the overall research project, as the use of VR hand controllers already limits users' hand gestures during interaction.

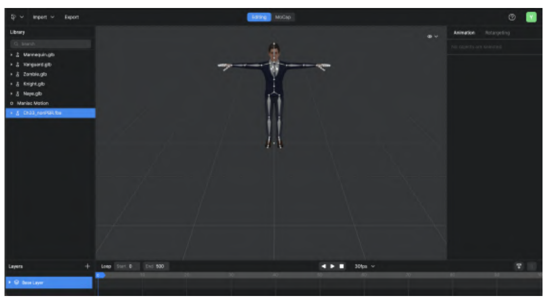

Fig. 10. Skeletal Tracking [107]

4.3 Design and Development of VR Prototyping

4.3.1 Space Design – K-pop Dance Studio

In the context of VR development, creating a virtual environment serves as the foundational stage where designers place interactive elements and establish spatial layouts. A useful platform for quickly setup is Sketchfab (Fig. 11) [108], an online repository that allows users to upload and share 3D models, which can then be integrated into game engines. Unreal Engine, widely used in the game and simulation industries, provides robust tools to simulate immersive VR environments. The chosen design for this project is a sci-fi-themed space [108] that mirrors the ambiance of a K-pop dance studio, setting the tone for an energetic and futuristic user experience.

A common approach in VR development is the use of pre-existing external assets—3D models and textures that have been previously created by other artists or developers. These assets are available in platforms like Sketchfab or the Unreal Engine Marketplace. By incorporating these existing models, designers can accelerate the development process and maintain a high level of detail in their environments without needing to model everything from scratch [109, 110]. This not only streamlines production but also helps to establish realistic spatial features such as depth, scale, and object boundaries. For example, using high-fidelity assets allows for better definition in lighting, shadowing, and texture mapping, giving the virtual environment a more intuitive and tangible feel.

The environment was initially modeled using Blender, a widely-used open-source 3D modeling software. Blender's intuitive interface makes it an ideal tool for creating complex virtual assets, which can later be imported into Unreal Engine for interaction and animation. Due to the limitations in visual fidelity of Unreal Engine 5's built-in low-fi modeling tools, higher-quality models were created in Blender. These high-definition models ensure sharper details and more realistic textures, essential for enhancing immersion in VR. In addition to environmental design, these high-fidelity models provide a sufficient volume of virtual space for interactive elements such as characters, objects, and dynamic movement. In the case of this VR project, these virtual spaces are designed to support smooth character animations, including complex avatar movements. The ability to manipulate and interact with these elements in real-time is a key advantage of VR, providing users with a sense of physical presence, referred to as embodiment in the virtual world.

In terms of model redesign, the imported model features a dynamic color scheme dominated by purple and magenta tones, with green as an accent color. This color combination was chosen to evoke a sense of vibrancy, excitement, and modernity, reflecting the dynamic nature of a K-pop dance studio and the theme of the movement study, *Maniac*. By carefully selecting this palette, the environment not only provides an aesthetically pleasing space but also enhances the user's emotional engagement with the VR experience.

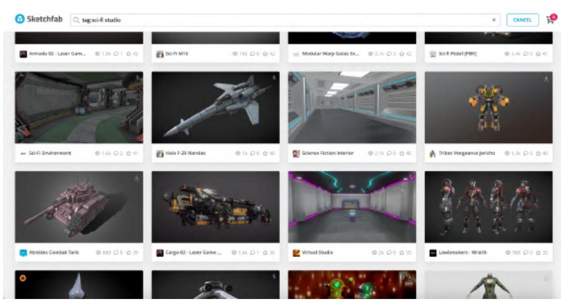

Fig. 11. Environment Setting from Sketchfab [108]

Fig. 12. VR Space Design

4.3.2 Virtual Avatar Design

In the design of dance experiences within VR, achieving a high degree of presence and immersion, requires a seamless connection between the user and their mirrored virtual avatar [33, 111]. This connection is crucial for creating the illusion that the user's physical movements are directly mapped to the virtual body, fostering a sense of control and engagement. To streamline the process, the T-pose mannequin was sourced from Mixamo (Fig. 13) [112], a free Adobe platform for 3D character animations. Mixamo provides fully rigged and skinned characters, pre-equipped with a digital skeleton for efficient movement and mesh deformation during animation. By utilizing pre-built assets from Mixamo [112], VR designers are able to leverage a wide range of existing characters and animations, which accelerates the prototyping phase. This is especially useful in dance-based projects where the precision and fluidity of movement are paramount. Moreover, Mixamo provides official tutorials and guides that detail the setup and application of skeleton-based movements, making it a valuable resource for junior designers or those unfamiliar with the intricacies of character animation. Designers often have to manually adjust the positions and orientations of skeletal joints in keyframes, which denote specific frames in an animation sequence that define the start and end points of movement, to accurately reflect complex dance movements [113, 114]. This involves fine-tuning the avatar's posture, limb rotations, and transitions to ensure that the dance moves are both realistic and smooth within the virtual environment. Additionally, hand gestures and facial expressions, while not always captured in basic animation workflows, may need to be manually added or refined to achieve a more nuanced and expressive K-pop performance.

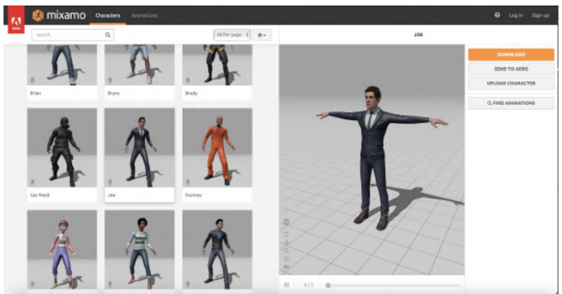

Fig. 13. Mixamo[112]

Fig. 14. Skeletal Rigging

4.3.3 *Virtual Choreography Design*

The VR prototype focused on incorporating the "Killing Part" of the choreography, often regarded as the most iconic and engaging segment, characterized by repeated and highly synchronized movement sequences [14]. In K-pop, synchronization is a critical metric for evaluating the precision and performance quality of a group, making it a key factor in replicating dance in virtual environments [32]. To accurately simulate this, the captured 3D movements were exported in FBX format, a widely-used file format for 3D animation, and imported into Unreal Engine 5 for further refinement.

In Unreal Engine, the movements were rigged onto a pre-modeled character following the animation pipeline as outlined in Plask's motion capture tutorial [107] (Fig. 14). Rigging involves mapping the motion-captured data onto the skeletal structure of the virtual character, ensuring that the avatar moves in sync with the original choreography. For the VR environment, the choreography was adapted into an interactive form, where users could engage with the dance moves in real time. Interaction design in this context requires adjusting the keyframe intervals and motion curves to ensure smooth transitions between poses, crucial for preserving the fluidity and energy of K-pop dance routines in VR. Additionally, synchronization was maintained not only in terms of avatar movement but also in timing the avatar's actions to match audio cues, a critical element for immersive dance experiences in VR.

4.3.4 *Interactive 3D Notation System Design in VR*

The objective of developing an interactive 3D notation system is to empower users to actively track the motion of the spheres, rather than merely replicating the virtual hand paths in the choreography without explicit guidance. Once the movements are blended onto the virtual character, a duplicate avatar is created, mirrored, and positioned appropriately to provide first-person perspective views. To enhance this immersive experience, spheres are attached to the wrists of the mirrored virtual avatar, effectively simulating the trajectories of the VR hand controllers (Fig. 15).

Fig. 15. Interactive 3D Notation System Example

As the animation initiates within the VR simulation, the mirrored character is hidden and invisible, allowing users to concentrate exclusively on the animated spheres, which are differentiated by color. Users are tasked with catching these spheres and aligning their trajectories with the moving paths. To account for user reaction times, the start of the moving spheres is set to occur 0.5 seconds earlier, optimizing the user's ability to respond effectively. As mentioned in the last section, this 0.5-second interval serves as a preliminary estimate, providing flexibility for future frame-to-frame observational studies aimed at further analyzing user performance and interaction dynamics.

Furthermore, an "overlap event" [115] is implemented to evaluate the precision of the alignment between the paths of the hand controllers and the trajectories of the animated spheres. This event is critical for assessing user performance and provides real-time feedback, enabling iterative learning and skill improvement. However, given that the animation duration is approximately 30 seconds, the resulting data may exhibit significant variability, highlighting the need for robust statistical analysis to derive meaningful insights.

Grounded in the frameworks of kinaesthetics and somaesthetics, this innovative approach is designed to assist practitioners (VR players) in identifying and visualizing the precise movements required for each K-pop choreography within a three-dimensional space. By escalating principles from embodied cognition, this method enables users to develop a deeper understanding of movement dynamics and spatial awareness, essential for mastering complex K-pop dance routines.

The interactive 3D notation system, enhanced with HCI choreography features, provides an equitable solution for individuals possessing varying levels of kinaesthetic knowledge to learn choreographed routines of K-pop dance in a VR environment. Moreover, the integration of advanced tracking algorithms and machine learning techniques can enhance the precision of the hand controller inputs and adapt the feedback mechanisms to suit individual user preferences.

4.3.5 Interface Design in VR

Unreal Motion Graphics (UMG), a built-in feature of the Unreal Engine (Fig. 16), is employed to create intuitive user interfaces in Virtual Reality (VR), thereby enhancing users' understanding of how to interact with objects and events within the environment. The interface and dashboard are designed to float centrally within the user's field of view, with each UMG component anchored at its center for optimal visibility and accessibility. Upon clicking a component, a change in hue and saturation occurs to signify selection, with a light purple color indicating the active state. This visual feedback is crucial for ensuring a seamless user experience, as it facilitates quick recognition and interaction with the interface elements, ultimately enhancing user engagement and interaction efficacy within the VR environment.

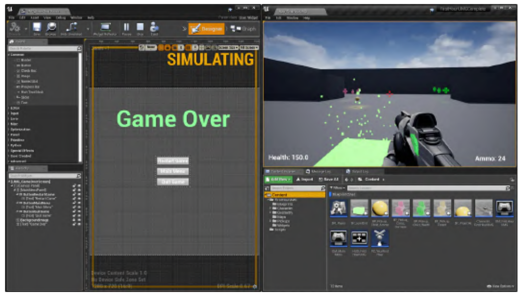

Fig. 16. Unreal Motion Graphic (UMG) Example [116]

The mock-up video illustrates the anticipated user interface flow for this VR prototype. The landing page is strategically designed to enable users to initiate the game and select their preferred song. Following this selection, users are guided to simulate the use of hand controllers by positioning their wrists at the center of the virtual spheres, a process that is critical for ensuring accurate interaction. Upon successful wrist alignment, the avatar representing the virtual hands is rendered invisible, allowing users to immerse themselves fully in the experience. As the selected song begins to play, the animated spheres serve as dynamic guides, directing users toward specific target positions and trajectories. This design not only enhances the immersive quality of the experience but also aids users in understanding movement pathways within the K-pop choreography.

After the completion of each song, the "overlap event" systematically calculates the percentage of alignment between the paths of the hand controllers and the trajectories of the spheres. This quantitative assessment is then presented to participants as their final score, providing immediate feedback on their performance. This scoring mechanism is integral to the learning process, enabling users to gauge their progress and refine their skills over time. By combining intuitive design with rigorous feedback mechanisms, this VR prototype aims to facilitate an engaging and educational dance experience for users.

4.3.6 Simulation in VR

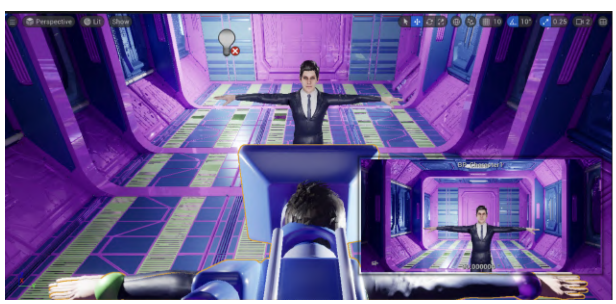

Fig. 17. Set Camera as First-person View

The integration of an Unreal Engine 5 project with the Oculus Quest 2 for immersive VR experiences can be accomplished through either Oculus Link or Air Link, allowing the VR headset to connect seamlessly with a laptop running the Unreal Engine project. In this configuration, the camera is set to a first-person perspective (Fig. 17), which significantly enhances user immersion and supports embodied somatic experiences. Within this VR setup, users engage in various interactive tasks, including hand perception, interaction with dynamic virtual spheres, and observation of a mirrored virtual avatar within a simulated K-pop dance studio environment. These interactions are facilitated through the laptop interface, enabling users to navigate and manipulate the virtual space effectively.

4.4 Autobiographical Study Structure

The autobiographical studies detailed in this research project (Table 1) are designed to collect first-person lived experiences, as articulated by Loke (2018). This methodology employs the primary researcher's body as a medium to explore both the limitations and advantages inherent in the self-evidence framework proposed by Schiphorst (2011). Recorded video data is analyzed frame-by-frame from a third-person observational perspective, as highlighted by Loke (2013). From this analysis, thirty frames depicting significant movement changes are selected for in-depth examination. The thematic analysis of the autobiographical study data systematically categorizes first-person lived experiences alongside third-person observations into distinct themes. These themes are organized under subtitles and integrated with theoretical frameworks drawn from somaesthetics, kinaesthetics, and HCI choreography. This novel approach not only enhances the understanding of individual movement experiences but also contributes to the broader discourse on the intersection of personal embodiment and theoretical constructs within dance and performance studies. By synthesizing personal narratives with theoretical foundations, the research provides a nuanced exploration of the dynamic relationship between the body and movement in interactive contexts.

	Video Reference by Hyunjin	AS 1: Cover of Original Choreography	AS 2: Dance with Hand Controllers	AS 3: Dance with Two Spherical Props	AS 4: Dance in VR (See Animation)	AS 5: Dance in VR (To Catch Virtual Spheres)
Equipments or Props	/	No	Hand Controllers	An Orange and an Apple	HMD and Hand Controllers	HMD and Hand Controllers, Laptop
Space	/	Dance studio with a mirror (8m depth)	Dance studio with a mirror (10m depth)	Dance studio with a mirror (10m depth)	Home (4m depth)	Home (4m depth)

The autobiographical studies conducted throughout this research are centered on acquiring new kinaesthetic knowledge within a virtual 3D space. This project utilizes self-observation and self-analysis of movement, based on autobiographical reflection, to collect first-person lived data, including somatic experiences. Consequently, the principal researcher serves as the sole participant in the study. For K-pop dance practitioners, the ability to accurately replicate movements observed in mirrored dance videos is critical. In the first three phases of the study, choreography is learned by watching example videos created by the original artists.

The initial autobiographical study was completed prior to the design of the VR prototype. The second study was conducted before the development of an interactive 3D notation system, while the third took place after conceptualizing the use of spheres to simulate hand movements. The fourth study occurred during the design process of the VR prototype, and the fifth study followed the creation of the user interface and its simulation in VR.

The first three rounds of autobiographical studies were recorded in a dance studio, where the presence of a large mirror was essential for simultaneous observation of reflected practice. Subsequent autobiographical studies, conducted after the integration of a Head-Mounted Display (HMD), were recorded in a larger room, requiring a space of at least 2m x 2m. This space allowed for full extension of the arms and ensured adequate room to perform the choreography.

5 Autobiographical Study Results and Insights

5.1 Autobiographical Study 1

The objective of the first-round autobiographical study (Fig. 18) is to identify potential challenges of the choreography by personally engaging in the K-pop dance cover practice. *Dance cover* [10, 40, 117, 118] serves as a tool for self-efficacy and learning independence in K-pop dance. Given that live performances and music videos of K-pop often emphasize precise synchronized dance [14], this study employs personal somatic feelings and self-observation to experience the movements and recognize difficulties [3, 45] that may not be replicated in Virtual Reality.

Fig. 18. Autobiographical Study 1 and Example Video Screenshots

The recorded videos have been analyzed frame-by-frame across six categories: (1) Device Interference Issues (HMD & Hand Controllers); (2) Precise Footwork & Pivoting Issues; (3) hand and Head Tilt Issues; (4) Hand Gesture Issues; (5) Fast Actions Changes Issues; (6) Hand cross Issues. The color-coding system has been introduced to visually distinguish each limitation, offering a classification framework for subsequent autobiographical studies.

5.2 Autobiographical Study 2

The objective of the second autobiographical study (Fig. 19) is to employ bodystorming technique to modify movements that are suitable for VR with hand controllers. Bodystorming, a useful technique in HCI choreography [20, 43, 119–124], is an embodied ideation method specifically designed for movement-based interaction, especially in interactive performance. This study provides first-person bodily experiences [54, 125], allowing designers to imagine possible forms of choreography during experiments.

From the recording video, hand gestures are physically restrained and perform more slowly compared to dancing without hand controllers, leading to the omission of some movements in the choreography. The inability to complete pivoting and precise footwork is found, which requires modifications to movements so that all face forward.

Fig. 19. Autobiographical Study 2 Screenshots

5.3 Autobiographical Study 3

The aim of autobiographical study 3 (Fig. 20) is to explore the physical constraints of virtual choreography with hand movement restrictions. Two props, an orange and an apple of similar sizes and shapes but different colors, are employed to represent the two virtual spheres in the VR prototype. These spherical props, rather than traditional hand controllers, are designed to physically limit hand gestures and body movements, allowing for an exploration of how such restrictions impact the replication of K-pop dance choreography.

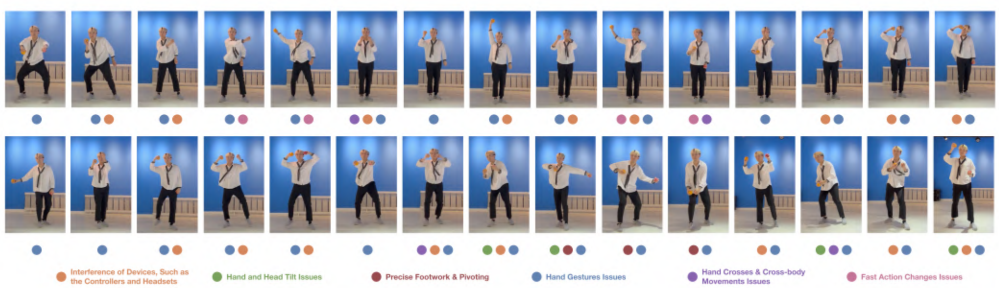

Fig. 20. Autobiographical Study 3 Screenshots

The study revealed that many hand gestures were compromised, as additional effort was required to hold the physical objects, a finding evident in key frames of the movement analysis. While the spatial gaps between the hands and the controllers were minor, approximately 5 cm, this discrepancy raised concerns about potential injury to the user's body and possible damage to the VR equipment. Moreover, the study identified challenges with downward movements, leading to diminished flexibility and fluidity in the performance of certain choreographic elements.

5.4 Autobiographical Study 4

The objective of this autobiographical study (Fig. 21) is to identify the limitations of VR hardware in designing for K-pop dance movements. Wearing the HMD significantly alters the sense of visual settings and perspectives. The video documentation captures the researcher's efforts to replicate K-pop dance movements from an example video. Immersed in a Virtual Reality learning environment, the researcher experiences enhanced self-awareness during dance practice.

The study reveals that, while the body is capable of moving freely in upward and downward directions, forward and backward movements are more challenging, with pivoting movements proving particularly difficult to execute.

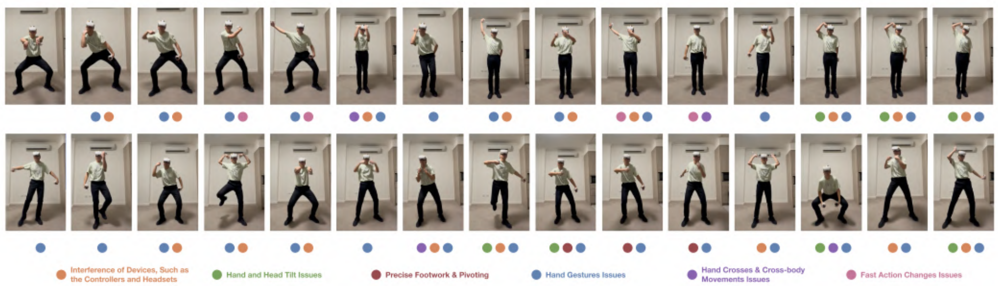

Fig. 21. Autobiographical Study 4 Screenshots

5.5 Autobiographical Study 5

The goal of this round of autobiographical study (Fig. 22) is to identify the limitations of the VR artifact and develop potential solutions to address these shortcomings. The lighting has been brightened, and an interactive 3D notation system has been added to the prototype. The user task is to use hand controllers to reach estimated positions and replicate the paths of moving spheres. Some movements have been identified as technically deformed and lack the accuracy of the choreography.

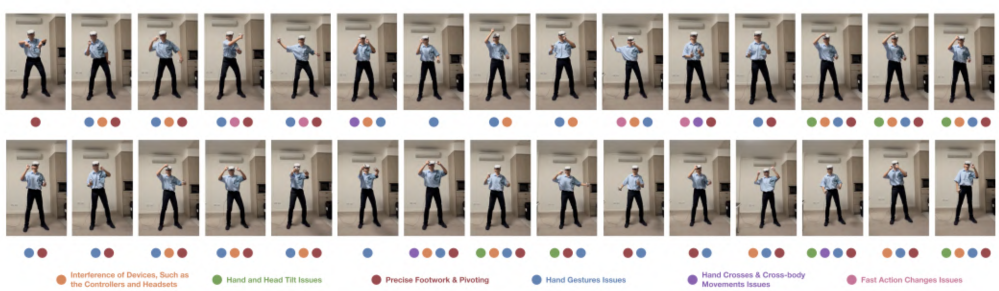

Fig. 22. Autobiographical Study 5 Screenshots

The overall reaction of the practitioner to the original choreography in this study is restrained. All footwork and pivoting movements cannot be achieved because there are no sensors on the legs or ankles. The upper body movements are shifted forward due to the thickness of the headset. Simultaneously, the positions of estimated targeting points are changed, but the researcher ignores this in the virtual artifact. In some scenes, the spheres cannot be seen, resulting in the omission of some movements. This occurs because of blocked views and the ergonomics of the VR headset. The distortion of movements is discovered, as only the wrists and head are simulated. The elbows and neck have moved into different positions, resulting in deformed movements. Surprisingly, playfulness and interactivity have improved in this round of the study.

5.6 Key Findings of Third-person Observation on Autobiographical Studies

	Accuracy of Choreography	Key Findings from Third-person Observations	Key Findings from First-person Perspective Experience
AS1	90%	• Have some fast actions and hand gestures • Attractive and recognizable "killing Part" • Complex footwork and dance techniques	• Feel tired and exhausted after practicing the choreography • Feel hard to follow the rhythm • The body always moves forward whilst dancing
AS2	65%	• Some **hand gestures** have been limited • Move less slowly than dancing without hand controllers, lose some movements • Cannot complete **pivoting movements**	• Feel **difficult to move down** • Fear of **hurting body and breaking machine** because of the gaps between hand controllers and hands
AS3	70%	• All **hand gestures** have been ignored • Lessen the gaps between hands and heads • The body is **difficult to keep down**	• Needs **extra effort** to catch the spheres • Feel **difficult to move down** and get more flexibility • Fear of **hurting body and breaking machine**
AS4	75%	• The **interference of HMD and hand controllers** happen several times • The range of **hand movements** increased • The range of **footwork** were limited	• Have better reflection and feel immersive learning how to dance by **copying avatar's movements** • Be conscious about hurting equipment and body
AS5	45%	• All footwork and pivoting movements cannot be achieved • All the upper-body movements have been moved forward **(due to the thickness of the headset)**	• The spheres in some scenes cannot be seen, resulting in failing completing some movements **(due to VR's ergonomics)**

The above table (Table.2) demonstrates the key findings of each round of autobiographical studies, based on frame-by-frame third-person observation and first-person experience. The accuracy of choreography has been estimated through observation, because the duration of the practice is only approximately 30 seconds. The comparison of each autobiographical study reflects how technical devices and visual elements impacts on user experience of movement-based activities.

5.7 Thematic Analysis of First-person Experience

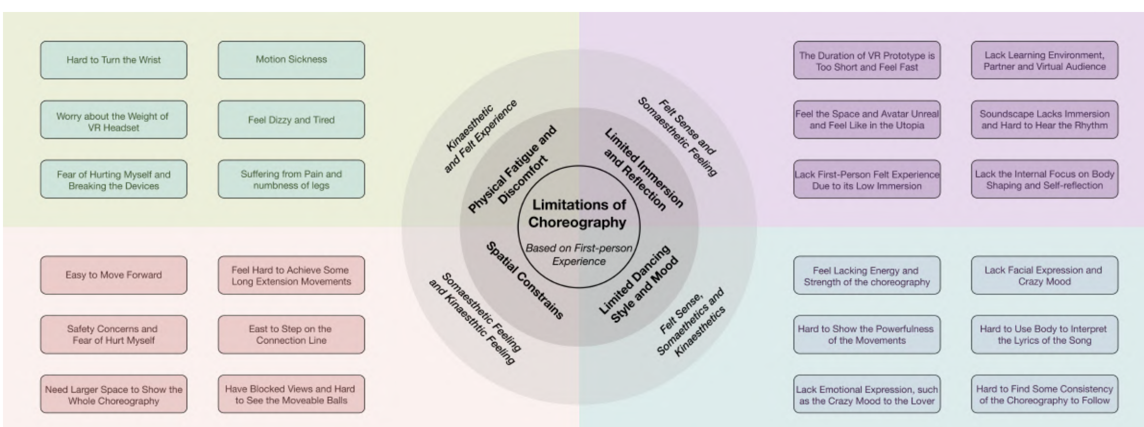

Fig. 23. Thematic Analysis

The autobiographical studies collect quantitative research data with first-person experience. The thematic analysis method, developed by Braun and Clarke (2006) in psychological studies, is a useful research tool to categorize the first-person lived data into valuable qualitative themes. The visual style of this thematic analysis (Fig. 23) refers Mah et al. (2021)'s autobiographic study and relates to the theoretical frameworks, such as kinaesthetics, somaesthetics and felt experience in HCI choreography studies [5, 25].

5.7.1 Physical Fatigue and Discomfort

Physical fatigue is a first-person somatic feeling related to the user's body and effort [71]. It has been felt in every round of practice, revealing varying levels of tiredness and exhaustion. From the second to the fourth study, full-body muscle pain and soreness are identified, which can be accepted as an uncomfortable somatic feeling whilst using incomplete props to simulate the choreography. In the fourth and fifth rounds, discomfort in the head is noted due to the weight of the VR headset. Moreover, in the first four autobiographical studies, the pain in the legs is identified, attributed to the original choreography, which involves complex footwork and requires extra energy to execute each movement. For boy's group dance in K-pop choreography, kicking and pivoting to emphasize masculinity and power is an integral part of the K-pop choreography [12], posing a challenge for Virtual Reality design. In the last study, fatigue primarily centers around upper body movements. Holding the hand controllers or the spherical props requires extra effort and becomes one of the elements resulting in physical fatigue. Additionally, twisting the wrists and making hand gestures while holding objects is challenging. After wearing the HMD in the fourth and fifth rounds, dizziness and motion sickness occurs during movement-based interactive activities. Moreover, subconscious fears of hurting the users' body and breaking the devices impacts some parts of the practices.

5.7.2 Spatial Constrains

Spatial constrains relates to the concept of the "Space" from Laban Movement Analysis [71] and somatic feelings [4]. In autobiographical studies 1 to 3, the primary researcher was able to dance freely, aided by the visibility of physical mirrors. However, in autobiographical study 5, conducted within a restricted space using an HMD and handheld controllers, the experience more closely resembled the typical VR user scenario. Although the virtual space projected through the HMD appeared boundless, occasional boundary warnings that were preset within the VR system were triggered, highlighting spatial constraints. This mismatch between the perceived virtual environment and the physical space contributed to somatic sensations of confinement during the VR experience. The physical constraints of VR technology limited the dancer's ability to fully execute these isolations and expressive movements, highlighting the challenges of translating intricate K-pop choreography, especially in terms of precision and stage presence, into virtual environments.

The first three rounds of practice took place in larger spaces, making certain movements easier to execute, particularly after complex footwork and pivoting. However, from the second to the fifth autobiographical study, performing long-extension movements, such as stretching the arms, became increasingly challenging. For the choreography of "*Maniac*", movements requiring forward and backward motion demand ample space. In autobiographical study 5, stepping on the connection cable posed a risk of stumbling. Additionally, some movements of the virtual spheres were obscured due to blocked views, leading to difficulties in catching them. As the sense of space shifted from a physical dance studio to a virtually boundless environment, the first-person experience transitioned from a feeling of security to anxiety about stepping into incorrect positions. In conclusion, spatial constraints were most evident in autobiographical study 4 and 5, arising from the mismatch between virtual and physical environments and limited visibility during VR interactions.

5.7.3 Limited Dancing Style and Mood

Dancing styles and moods vary among practitioners as a result of differing levels of kinaesthetic knowledge and somaesthetic perception. These variations influence how dancers interpret and execute movements, shaping their individual expression and emotional engagement within the performance. In the study of Stray Kids' "*Maniac*", the choreography is characterized by its sharp, dynamic isolations and power moves, reflecting an edgy aesthetic that conveys stories of individuals challenging societal norms and expectations. However, embodying the precise musicality and attitude required for this performance presented challenges throughout the autobiographical studies. The bird-flying hand gestures, extending outward from the mouth, serve as signature moves that synchronize with the chirping sounds in the music. These gestures, integral to the storytelling aspect of the choreography, proved difficult to replicate due to haptic limitations, particularly when wearing an HMD and using hand controllers in autobiographical studies 4 and 5.

Furthermore, conveying the energy and strength in the choreography becomes challenging from autobiographical study 2 to 5, particularly when holding spherical props or hand controllers. In autobiographical study 5, the task of catching virtual spheres results in softer movements lacking energy. One possible reason is the task of replicating the path of the spheres lacks animated notations indicating the requires strength to catch them. With concerns about self-injury and device damage, achieving the same strength as the original choreography becomes elusive.

5.7.4 Limited Immersion and Reflection

Immersion and reflection is a key criterion that need to be identified in VR studies [33], relating to somatic feelings and felt sense. For autobiographical studies 4 and 5 specifically, immersion and reflection in Virtual Reality experiences are related to the felt sense and individual's somaesthetic feelings. However, the VR prototype's brevity and slightly fast speed hinder accurate replication of movements from the avatar or example videos, creating an unreal and alien sense in both space and avatar representation.

In traditional dance learning experiences, music typically plays at a high volume to ensure dancers can hear clearly. However, the soundscape in the VR prototype lacks immersive qualities and makes it challenging to catch the rhythm. Compared to traditional practices, dancing with VR prototype lacks rapid feedback, with results on the accuracy of the choreography only appearing at the session's end. Real-time virtual avatars offering tips or signals could be a potential solution to enhance feedback.

6 Discussion - Limitations, Advantages and Future Work

The discussion in this research project is two-fold, critically examining both the advantages and limitations as crucial design considerations when developing VR artifacts. Navigating and mitigating existing limitations while leveraging their unique advantages is imperative to enhance user experience. VR enhances engagement and immersion beyond physical limitations, enabling users to explore and embody intricate dance movements with precision and creativity in the field of HCI choreography.

6.1 Technique Limitations of Devices

6.1.1 Interference of Devices, Such as the Controllers and Headsets

The most recognizable movement sequence, involving tilting the head and twisting the left wrist, faces technical limitations due to device interference such as controllers and headsets (Fig. 24). The immersive quality of VR dance with K-pop choreography relies heavily on precise tracking and responsiveness of these devices to accurately translate

Fig. 24. Interference of Device Example

physical movements into the virtual realm. However, device interference can manifest in various ways, affecting the dancer's experience and imposing constraints on choreographic expression. For instance, in autobiographical study 5, the movements of twisting the wrist near the head were hindered by accidental contact between hand controllers and the HMD. Controllers, essential for user interaction, are pivotal in executing choreographed movements, yet their physical presence in users' hands can disrupt the natural flow and kinaesthetics of dance. Despite alterations and missed movements in autobiographical studies 4 and 5, issues like visual occlusion and potential disorientation further complicate the choreographic process. Understanding the impact of device interference presents opportunities to enhance the technical aspects of VR dance choreography, ensuring a safer and more immersive experience for practitioners.

6.1.2 Hand and Head Tilt Issues

Fig. 25. Hand and Head Tilt Example

The recognisable movements with tilting the head and twisting the wrist for three times with different angles (Fig. 25) in the choreography of "*Maniac*", has been identified deformation in terms of missing head tilt and arm positioning. Thus, it has been identified that the hand controllers hit the HMD accidentally during this movements several times. Even if all the hand gestures have been simplified or even ignored in the autobiographical study, the fidelity of hand-tracking technology determines the level of detail with which dancers' gestures are replicated in the virtual environment. Challenges sometimes arise from occlusions, where the sensors lose sight of the hands, leading to inaccuracies or delays in movement representation, especially for completing the tasks of catching the virtual spheres. However, technical limitations in head-tracking systems may result in discrepancies between the user's actual head movements and their virtual representation. This misalignment can disrupt the sense of presence and compromise the overall kinaesthetic coherence of the choreography.

6.2 Kinaesthetic Limitations (Dance Technique)

6.2.1 Precise Footwork & Pivoting

This experiment relied solely on inside-out tracking sensors associated with handheld controllers within a restricted 2m x 2m space, presenting significant challenges in accurately capturing lower body movements without external trackers. Observations from autobiographical studies 2 to 5 revealed that precise footwork and pivoting emerged as considerable hurdles in the design of HCI choreography. In autobiographical studies 1 to 3, it is noted that moving forward, especially after pivoting or turning, was relatively easy to achieve. However, dancing in VR requires constant attention to the HMD and facing forward, making pivoting an impractical task in autobiographical studies 4 and 5 (Fig. 26).

Fig. 26. Pivoting Example

K-pop dance, known for its intricate synchronized movements and dynamic footwork, faces significant challenges when adapted to a virtual setting. A primary concern is the difficulty in executing accurate footwork and pivoting movements due to the lack of sensors on the legs or ankles in most VR systems. In contrast to games like *Dance Dash*, which utilize external sensors to capture leg movements, this study focuses on the replication of upper-body movements. Autobiographical study 3 specifically emphasizes the limitations in performing intuitive footwork, as the spatial tracking of lower limbs remains a persistent technological challenge. The absence of precise feedback regarding the position and orientation of the feet inhibits users' ability to authentically execute intricate foot movements. Moreover, the limitations inherent in VR technology complicate the replication of the detailed footwork characteristic of K-pop choreography. Achieving the precision typically seen in traditional dance studios, where mirrors assist performers in refining their movements, becomes complex within the virtual environment. Autobiographical Study 5 highlights the difficulties encountered when attempting to complete pivoting movements. The constraints of the physical space in this study and tracking limitations hinder users' ability to execute seamless rotations, as the restricted spatial conditions and the lack of real-time visual feedback impede the maintenance of accuracy and alignment essential for executing intricate footwork.

6.2.2 Hand Gestures Issues

According to autobiographical study 1, hand gestures play a significant role in conveying the meanings of lyrics and music. Movements such as shaking hands, face-touching, rock-and-roll gestures (Fig. 27), head-hitting, bird-flying-like gestures, and others are integral to interpreting contextual meanings and emotional significance. However, when

Fig. 27. Hand Gestures Example

holding hand controllers and spherical props, most hand gestures become constrained or even ignored. Twisting the wrists, as observed in autobiographical study 5, becomes a challenging task to achieve. These constrained gestures also contribute to technical limitations, such as interference of devices. The physical constraints imposed by hand controllers may limit the range of expressive hand movements, hindering the natural articulation of fingers and palms. Addressing the issue of full-body movement and haptic feedback needs to overcoming the limitations of hand gestures in VR dance [33]. Traditional practices of K-pop dance relies on tactile sensations for movement navigation, while VR systems focus on visual and auditory feedback. Autobiographical studies 2, 4, and 5 highlight that the absence of haptic feedback in hand gestures can impact the user's sense of immersion, requiring innovative solutions to bridge this sensory gap. To conclude, adapting hand gestures from the physical to the virtual space presents challenges in maintaining cultural significance and contextual meanings.

6.2.3 *Hand Crosses & Cross-body Movements Issues*

Fig. 28. Hand Crosses Example

According to the autobiographical studies 4 and 5, addressing hand cross and cross-body issues while holding the hand controllers is crucial due to potential risks of injury to the body and devices. In comparison to autobiographical studies 2 and 3, the researcher focused less on hand movements while observing virtual representations in the HMD, which may lead to accidental interference. Additionally, the thickness of the hand controllers prevents the movement of clasping palms (Fig. 28), requiring gaps between the controllers to ensure safety. The technology's precision in discerning spatial relationships between the user's hands, arms, and body makes challenges for authentic and immersive choreographic experiences. Hand cross and cross-body movements involve intricate spatial arrangements and precise timing. Delays, inaccuracies, or a lack of responsiveness in the tracking system may compromise the user's ability to execute these choreographic elements seamlessly. HCI choreographers need to adapt original K-pop dance movements to the unique affordances and limitations of VR, particularly for intricate gestures involving hand crosses and cross-body interactions. This adaptation ensures that virtual choreography remains artistically compelling and aligns with the technical capabilities of VR systems.

6.2.4 Fast Action Changes Issues

Fig. 29. Fast Action Changes Example

Due to the original choreography's rapid action changes identified in autobiographical study 1, practices in Virtual Reality encounter heightened challenges. Particularly in the early stages of VR prototyping, personal practices have shown difficulty in maintaining movements and achieving objectives, such as the movements of swing arms in autobiographical study 2 (Fig. 29). The ability to execute quick and dynamic movements is essential in dance, and translating such actions into a virtual environment requires meticulous technical and experiential considerations. Limitations in VR sensor processing speeds can hinder the seamless translation of rapid actions, compromising choreographic fidelity. Additionally, the design of VR interfaces and controllers is crucial in addressing rapid action changes. Delays or unresponsive hand controllers can create a disconnect between physical exertions and their virtual representation. From a choreographic perspective, HCI choreographers and developers must explore methods to optimize motion-tracking technologies, deeply understand kinaesthetic knowledge, and design intuitive interfaces that facilitate the smooth execution of rapid dance movements.

6.3 Somaesthetic Limitations

6.3.1 Subconscious Reactions and Muscle Memories

The primary researcher in this study is a K-pop dance practitioner who familiarized with the original choreography, "Maniac," prior to undertaking research and autobiographical studies. This prior experience may have resulted in the development of muscle memories within the researcher's body, potentially leading to varied reactions during certain movements. The intricacies of subtle gestures, muscle contractions, and intuitive bodily responses can encounter limitations when interacting with technology that relies on explicit input or predefined algorithms. Addressing these somaesthetic challenges necessitates a nuanced understanding of how bodily experiences intuitively engage with movement and aesthetics [3], alongside innovative approaches to capture and interpret subconscious reactions and muscle memories within the evolving landscape of interactive K-pop choreography.

6.3.2 Artistic Boundaries in Virtual Choreography

Dance, as an art form, needs aesthetics and artistic considerations. Facial expressions, emotional expression and hand gestures are integral parts of K-pop performances [12], and managing facial expressions is a key task for professional K-pop dancers. According to thematic analysis, the challenge of embodying personal somatic feelings in Virtual Reality arises from adhering to designated interactive 3D paths of set choreography under the theme of 'limited dance style and mood'. Despite the same choreography being performed by different members of K-pop groups, personal styles and movement details are interpreted variably based on diverse kinaesthetic knowledge, somaesthetic feelings, cultural background, and understanding of the music and lyrics.

6.3.3 Autobiographical Studies Involving Narcissism and Self-Serving Activity

The participant in this research project is only the primary researcher, which raises considerations regarding biases related to individual body consciousness and awareness [16, 18]. Critiques of narcissism and self-serving behavior are common in autobiographical studies. However, agreed with the viewpoint of Loke & Schiphorst (2018), this concerns is not narrowly constrained to individualistic self-serving activities, but rather an approach to examine and empathy the artifact in a human-centered method. While each dance practitioner exhibits unique personal styles, felt senses [55], and preferences, there exist universal somatic principles that can guide fellow designers interested in developing similar artifacts.

6.4 Ergonomic Limitations of the Hardware

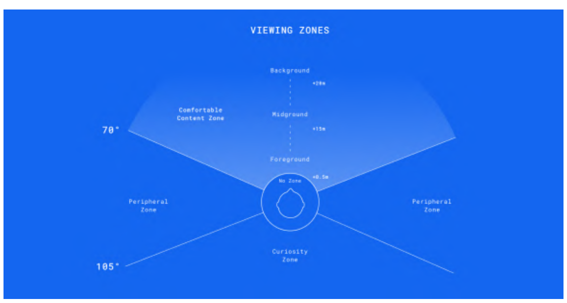

Fig. 30. Comfortable Content Zone in VR [127]

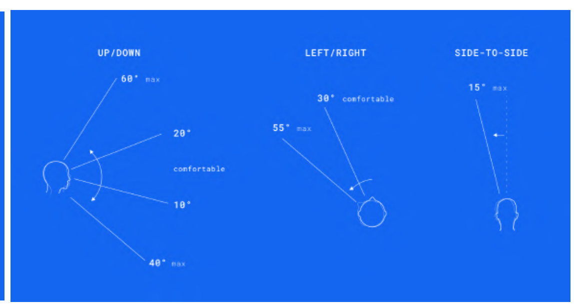

Fig. 31. Comfort Zone in VR [127]

In Autobiographical Study 5, some segments of the interactive 3D notation paths, especially those located near the sides of the head, were not visible through the VR headset when the participants faced towards the same direction. The comfort zones (Fig. 30 and 31) provided by VR headsets significantly influence the design process, as issues such as motion sickness, eye strain, and spatial awareness can pose potential risks if ergonomic principles are not properly applied [127, 128]. Integrating ergonomics into the development of VR prototypes emphasizes user-centered design approaches, aiming for adjustable, customizable, and user-friendly interfaces.

In VR dance choreography, the interaction between head and hand movements is critical in determining how dance practitioners engage with the virtual environment and express themselves with somatic awareness. Skeletal tracking, as implemented by OpenPose in 2022, identifies key points such as the head, shoulders, elbows, wrists, hips, knees, and ankles [129], yet only the head and wrists are simulated within the VR prototype. The limited tracking key points can be regarded as a contributing factor to the technical deformations observed in movements during Autobiographical

Study 5. Head movements in VR enable dancers to explore the virtual space, orient themselves, and navigate similarly to how they do in the physical world. However, in contrast to VR, the visual perspective in the real world does not rotate in response to head movements, due to the inherent ergonomics of the HMD. Hand movements, tracked by the VR controllers, are essential for choreographed interactions. However, they also impose limitations on the dancer's ability to perform precise gestures and replicate choreography with full accuracy. At times, VR users may inadvertently drop the controllers when attempting complex hand gestures. This misalignment between real-world practice and VR-based activities, particularly concerning dance movements, must be addressed to ensure both safety and the preservation of movement aesthetics.

Furthermore, the balance between head and hand movements ensures that dancers can seamlessly navigate through the K-pop choreography while maintaining spatial awareness and high synchronization with the music. For instance, dancers could use head movements to follow a virtual avatar's gaze, while simultaneously using hand movements to perform intricate dance gestures or interact with virtual props. The K-pop choreography featuring waacking style, with quick arm movements using angular and dynamic poses, can provide more design opportunities in HCI choreography, but also pose challenges for users with less kinaesthetic knowledge. Examples, such as "Flower (2023)" by Jisoo, "Queencard (2023)" by (G)I-dle and "Super Shy (2023)" by NewJeans, emphasizes sharp and precise movements of the arms and hands, contributing to a more dynamic and expressive nature of the HCI choreography. These examples can be applied as close studies for emerging HCI practitioners who wish to develop K-pop choreography in the virtual realm.

6.5 Advantages of Dance in VR

6.5.1 Playful, Immersive and Interactive Learning Experiences

Compared to physically attending traditional dance classes at studios, learning K-pop dance in VR offers a transformative educational experience for dance practitioners. The immersive and interactive nature of VR introduces a playful element that encourages curiosity and experimentation, fostering a sense of agency and connection with the virtual environment. Through the use of headsets and controllers, users actively participate in the learning process, contributing to an interactive educational experience enhanced by somaesthetic consciousness and awareness [16, 18]. This interactivity enables users to engage directly with choreographic elements, replicate movements, and acquire kinaesthetic knowledge, thereby exploring human potential through new technology.

6.5.2 Accessible Training and Customizable Environments

Compared to traditional dance training methods, VR enables the creation of virtual dance spaces that cater to individual preferences and needs, transcending conventional limitations. Accessibility is markedly enhanced as users engage in dance training from their homes, overcoming geographical barriers and offering scheduling flexibility. Customizable VR environments allow users to tailor training spaces to personal preferences, fostering a more personalized and immersive learning experience. The use of headsets and controllers facilitates interactive and dynamic training sessions, enabling users to adjust the pace and repeat sequences as needed. This approach aligns with contemporary HCI theories that emphasize user-centric design and personalized learning experiences[130]. By integrating accessible training and customizable environments, VR dance choreography represents a significant leap towards inclusive, adaptable, and engaging dance education for diverse participants.

6.5.3 Exploration of Human Potentials in Innovative HCI Choreography

Even though the study finds that the potential interference of devices may hurt the users, the innovative choreography facilitated by VR extends beyond traditional dance methodologies. Utilizing VR allows users to experiment with movements within an immersive environment, fostering a boundless space for exploring new choreographic ideas. This aligns with the principles of bodystorming, an embodied iteration method in HCI [3, 20], which encourages choreographers to physically immerse themselves in virtual scenarios to generate creative physical ideas. This convergence represents a significant advancement in the intersection of new technology and HCI choreographic exploration, contributing to the transformative exploration of dance practices in the digital era.

6.6 Future Work

The future design process should capitalize on the strengths of the current VR prototype while integrating insights gained from previous iterations. Given the constraints of time and workload, it is crucial to systematically examine potential technical limitations in developing movement-based interactive artifacts in future studies. Refining the VR prototype through comprehensive user testing, which includes participants with varying levels of kinaesthetic knowledge, will be essential in creating more accessible digital choreography in VR. Furthermore, considerations for special user groups, such as individuals with visual impairments or physical constraints, must be actively explored in subsequent design iterations. As VR experiences increasingly shift towards social platforms, incorporating multiplayer functionality with diverse digital avatars within a 3D environment can significantly enhance collaborative and educational aspects. With the impending release of Just Dance VR on October 15th, 2024, additional innovative insights will likely emerge through first-person experience with this new product. This research aspires to inform the development of future commercial VR products, contributing to more inclusive, intuitive experiences for a broader range of users.

For emerging designers, creating VR dance choreography requires a grounded understanding of how users interact physically with virtual environments, focusing on physical sensations and bodily experiences [3, 16, 23, 54] inherent in movement-based interactions. Mastery of kinaesthetic principles and nuances specific to dance genres enables designers to develop interfaces that intuitively respond to users' physical inputs, thereby enhancing immersion in VR dance experiences. HCI choreographers need to understand intricate qualities of bodily experiences, exploring how movements and interactions elicit kinaesthetic responses. This interdisciplinary approach with self-reflective method, emphasizing the integration of sensory aesthetics and embodied self-evaluation to craft compelling and immersive VR dance environments. These insights are transferable to applications in AR, MR, and XR extensions, further advancing interactive and engaging digital experiences.

7 Conclusion

Immersive virtual K-pop dance performances transcend traditional human physical movements, demanding precise kinaesthetic knowledge and first-person embodied experience for effective design. This research focuses on the development of an interactive digital artifact of K-pop choreography, emphasizing high synchronization, precise set choreography and the fusion of diverse dance genres. This study offers a novel methodological framework for future HCI research, integrating machine learning software into movement-based design, evaluating dance practice through self-reflection, and refining interactive experience in 3D virtual environments. Employing a reflective approach via five-round autobiographical studies, it utilizes bodily experience as a participatory lens to comprehend interactive movements in virtual reality. Through autobiographic studies with thematic reflection, the VR prototype identifies (1) technical limitations of devices; (2) kinaesthetic limitations of dance technique; (3) somaesthetic limitations related to embodiment of emotion, personal style and individual somatic feelings. Therefore, this research contributes to designing interactive and immersive performances by integrating ML-based skeletal tracking in movement design, prototyping VR-based artifact to understand the HCI choreography, and evaluating digital prototypes' feasibility through human embodied experience.

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A video of the VR prototype with reaction of the autobiographical study 5 can be found here: https://www.youtube.com/watch?v=v-sHT3GaZxc

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