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Design and Implementation of a Virtual Reality Experience System Incorporating Popular Music and Dance

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Abstract: In this paper, we introduce a design of immersive virtual reality system that combines pop music and dance to attract the user and bring them the entertainment experiences. Using motion capture, real time audio analysis, and 3D visualization, the proposed approach generates an interactive scenario in which users learn, perform, and experience dance choreography to pop music. The system architecture is based on the Unity3D game engine and the Oculus Quest 2 VR headset, combined with in-house motion tracking algorithms to offer a dynamic and fun experience. We investigated learnability, immersion, and learning effectiveness through two user studies involving three age groups with 45 participants in total. The VR dance app scored 78.4 on average in the SUS. The74% of respondents reported to have improved significantly in dancing, and 83% to feel they were performing better. The system latency was limited to less than 20ms to maintain synchronization of user's movement and feedback in the virtual world. This work advances the development of VR-based entertainment and education, and establishes that music and dance may be leveraged as sources of fun and learning in virtual worlds.

Keywords: Virtual Reality; Dance Education; Pop Music; Motion Tracking; Immersive Learning; Human-Computer Interaction; and Entertainment Technology

1. Introduction

VR is human-born prejudice to the writer no doubt entirely without reason in his age and 40 years ago it seems that WithVirtuality was an intelligent reader. It has allowed for greater depth of immersion in entertainment, teaching, and health-care experiences. Since the synthesis of music and dance in VR [1] is definitely one of the most exciting application the reason is that sound, sight and movement can be merged to create multisensory experiences. Since pop music is very popular among young people and its rhythm could suit well with VR, so it can be selected as background music for the VR dance game. It also seems like a lot of folks can relate to some of the things she sings about. The combination of these ingredients caters, as they now seem to, to the increasing demand for interactive fitness applications, remote education, and new forms of entertainment, the momentum of which is gaining in today's digital society [2].

The incentive to develop a VR dance system is drawn from several key findings in the current entertainment and exercise industries. To learn how to dance the old fashioned way you need to be there and have expert teachers and you need to put in a lot of time. That's not so great for people who just want to learn to dance [3]. In addition, the COVID-19 pandemic has further promoted the migration of face-to-face activities to online and virtual modes, highlighting demand for solutions that work effectively in the digital environment. VR does have some things that traditional video-based dance classes can't have. For example, it provides spatial consciousness, real-time feedback and dance studio-like environmental features [4]. With such features, users can visualize where their body is in three-dimensional (3D) space, receive corrections instantly, and get the sense as if they are in a virtual dance hall [5].

Dance mechanics in the VR should be satisfying, and could even have a bit of a physical workout aspect, but solid VR dance experiences are ludicrously hard to make from both an experiential and technical standpoint. A high-accuracy motion tracking system is required to track subtle body motions without causing motion sickness or disorientation due to latency [6]. It needs to pace the user's dance to the music beats, give crisp visual signals, and positively assist users without distracting them. And you have to split the choreographic material up and the different levels of people are able to access it and still challenge them [7]. The realization of a satisfactory and harmonized system to fulfill these requirements calls for an all-inclusive consideration to hardware selection, software design, user interface development, and content mediation [8].

This paper addresses these challenges and the others 6 by presenting a full VR dance game experience system based on pop music and interactive choreography tutorials. We created a new architecture for real-time motion analysis and feedback, a content pipeline to convert stage professional choreography into VR compatible format, and a method to evaluate [9] the effectiveness through user study under controlled condition. The system implements beat tracking algorithms to synchronize visual cues with musical components, a gradual difficulty ifrstro to facilitate learning, and a multimodalfi feedback system based on visual overlays, haptic sensations, and user performance scoring. We demonstrate that VR- dance experiences can be: feasible and meaningful through a series of systematic studies examining areas such as usability, immersion, learning effectiveness, and system performance [10].

2. Related Work

The confluence of virtual reality, music, and dance has attracted considerable scholarly inquiry in the past decade, resulting in a variety of approaches to the design of immersive experiences. Initial work in VR dance systems focused attention on the visualization and spectating aspects and was only peripherally concerned with participation [11]. Scientists have also studied with virtual reality to create virtual concerts and dance performances, in which you can watch professional dancers from multiple angles in 360-degree environments. These demonstrated that music entertainment could be done in VR, but there wasn't much interactivity. Later ones included motion tracking so that people could participate [12]. Dance Central VR and Beat Saber are the very first commercial games to successfully meld rhythm-based gameplay with physical movement. Still, the apps were more about having fun than taking actual dance lessons, and more often than not, they featured abstract or simplified moves instead of actual choreography.

Scholarly research has been conducted on various procedures for capturing and analyzing motion in dance [13]. Recently, some computer vision-based approaches that apply RGB cameras or depth sensors as sensing devices have been proposed, which can capture the dancer's movement without any wearable sensors [14]. This makes the technology a bit friendlier. With the evolution of machine learning, particularly pose estimation algorithms such as OpenPose and MediaPipe, it is now possible to track bones in real-time with sufficient accuracy for dance analysis. Researchers have also investigated methods to match a user's motion to a reference choreography [15]. They applied algorithms such as DTW (Dynamic Time Warping) as well as pose similarity metrics to provide performance feedback. Some have even included gamification elements, scoring systems, and levels of increasing difficulty to foster the best learning and motivation. These technical core components also play a crucial role for VR dance systems, however, they are often individual components rather than integrated systems [16].

Dance step alignment with music relies on the MIR (music information retrieval) and audio analysis techniques. Beat tracking algorithms detect rhythmic patterns in music, allowing systems to provide visual cues and feedback in time with the music [17]. Tempo estimation, downbeat tracking and structural segmentation are all used to segment dance moves into meaningful segments compatible with the music. Recent research can be found in the use of audio features, such as energy, spectral content and onset detection, to generate movement suggestions or to modify the composer profile dynamically. Some systems rely on machine learning to analyze the relationship between different parts of the music and dance moves [18]. That could enable automatic choreography generation. Nevertheless, it is difficult to bring these attributes of audio analysis to VR applications and keep up with real-time execution, especially when considering the synchronization of multiple data streams such as music playing, motion capturing, and visual rendering.

User experience research in VR dance has yielded useful design recommendations that make these sorts of applications feasible and enjoyable. The effect of variables on presence, immersion and flow of the virtual reality dance environment has been explored and potential factors such as visual feedback quality, movement-sound synchronization, and spatial audio use [19] have been suggested. All work on www and volatility of resolution of all studies on cybersickness has shown the need to keep frame rates high, latency low, designing movement regimens with the least possible disorientation. Multiplayer frameworks and shared virtual dance environments have explored the social aspect of VR dance, indicating that it can be used for collaborative engagement and community creation at [20]. Barriers to accessibility, including allowing users of all physical abilities to make use of the software, enabling users to access varying levels of difficulty, and designing interfaces that a wide variety of users can utilize are among the concerns addressed. These are the human factors results that assist the designer's decisions, but should be cautiously weighed against what is technically feasible and can be implemented [21].

3. Methodology for Design

3.1. The structure of the system

With the VR dance experience proposed, the system architecture is designed to be modular with five components: the VR interface layer, the motion tracking module, the audio analysis engine, the choreography database, and the feedback generation engine. Based on Unity3D version 2021.3 LTS the VR interface layer manages the visual environment of the Oculus Quest 2 headset, User Interface (UI) elements and the rendering pipeline [22]. This layer creates the virtual dance studio environment, with options such as professional stage and casual practice room. It also display visual guidance components such as transparent avatar overlays that indicate the correct positions and trajectory lines that indicate where movements will take place as shown in Figure 1.

The motion tracking module relies on data from the Quest 2's integrated sensors and optional body tracking accessories to monitor users' movements live. We used a hybrid tracking method that combines the headset 6DOF tracking with IK to infer the full-body pose from the head and hand positions [23]. For extra accuracy, the system is also compatible with Vive Trackers which can be mounted to the user’s feet and hips. The tracking data is subjected to filtering using a realization of Kalman filter so that it is less noisy but still responsive. At 90 Hz, joint positions are extracted and mapped to a generic skeletal structure, which is then used by choregraphy comparison algorithms [24].

The audio analysis engine processes pop music tracks in real time, extracting rhythmic and structural information which is also used to synchronize dance moves. We used the madmom library’s DBN beat tracker to detect beats. This method applies dynamic Bayesian networks to precisely detect beat locations even in extremely complex musical textures. The system calculates tempo, time signature and also divides tracks into high level segments such as verse, chorus, and bridge. We extract audio features such as spectral centroid, energy and onset strength to give us additional insights into style and energy of movement. To prevent rendering performance from being impacted, all of the audio processing is done in one thread.

3.2. Choreography Content Pipeline

To produce choreography content suitable for VR, the professional dance performances must be converted into choreographic notation that the system can then visualize and rate. Our content pipeline begins by taping professional dancers performing choreographed dance routines. These videos are processed with Open Pose to extract skeletal pose data for each frame. This provides us with a sample of time series data of the joint positions in the performance. Dance teachers can utilize a custom annotation tool to split up choreography into bite-sized chunks, four to eight count phrases that correspond with the musical structure. They may also assign a level of difficulty to each group, provide a list of the skills required to complete it, and more descriptive meta information, as shown in Figure 2.

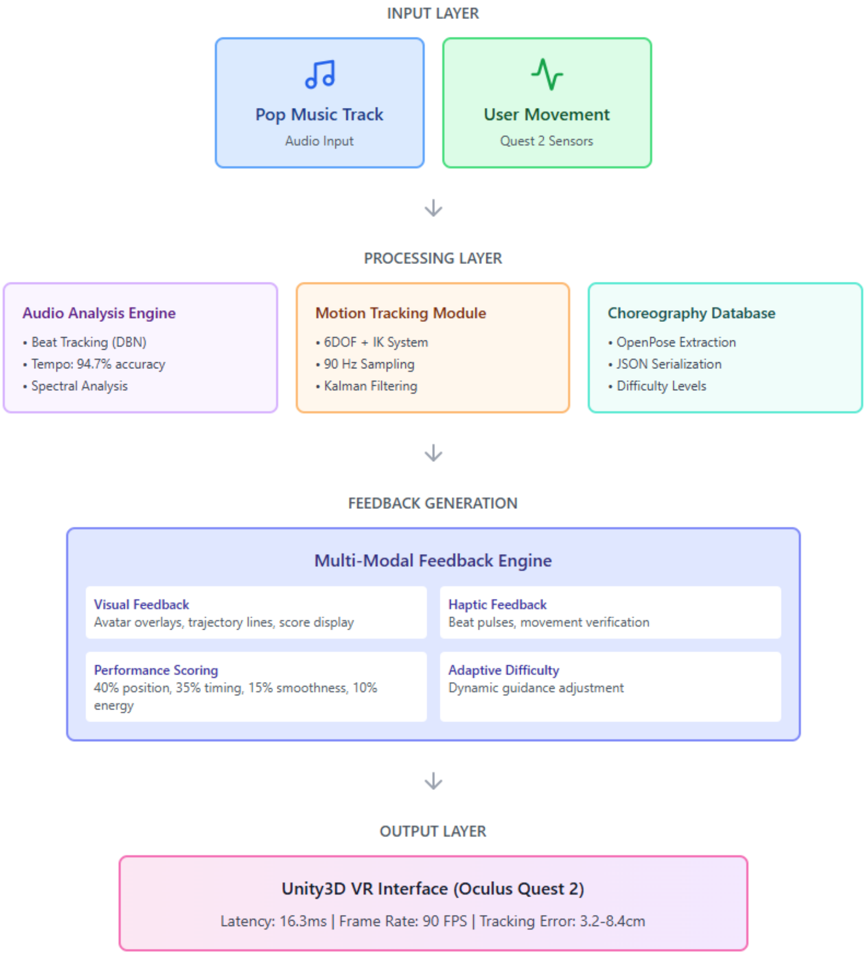

Figure 1. System Architecture Flow Diagram

The normalization and the enhancement of the extracted pose sequences ensure consistency between pose sequences from different performances of different subjects. In order to make it user-friendly for people with different body types, scale normalization is applied based on the length of the bones in the body. Then principal component analysis is applied in order to reduce the size of data while retaining necessary motion characteristics. There is timing information that is associated with each choreography segment which is linked to the audio track that corresponds with it. This data includes the start time, duration, and the beat alignment within the music. The processed choreography is serialized into a JSON structure which features pose keyframes, timing metadata and difficulty parameters along with instructions.

3.3. A system for interactive learning

The learning system adopts a progressive approach and adapts to the abilities and learning paces of the users. Teaching choreography has three phases: demonstration, practice, and performance. When in demonstration the users observe a virtual instructor avatar perform the entire choreography sequence while the system flags key moves and verbally instruct on how to perform them [25]. The playback rate can be adjusted, users can stop at certain segments, and observe the moves from different angles, including first-person, third-person, and birds-eye perspectives.

You can practice, too -- there are options to perform segments of the choreography at reduced speed with plenty of visual assistance. The active game pad is the system for now showing a translucent overlay avatar representing the correct poses in advance of the current music timing. This gives users a way to anticipate what the nexts moves will be. The lines of trajectory represent the path that the hands and feet take through space. A rhythm guidance system provides you with visual and haptic beat notifications by causing the controller to vibrate rhythmically following the beats of the music's emphases. The system continuously monitors a user's movements and evaluates them against the reference choreography using a combination of joint position similarity, timing accuracy and motion smoothness-based metrics.

In performance mode, you must perform the entire routine at full speed without much assistance from the visuals. The system records scores automatically, calculating the score on the player's movement, adherence to timing, and style execution. Scoring is based on a complex weighted calculation of the positional accuracy (40%), the timing accuracy (35%), the movement smoothness (15%) and the energy matching (10%). Users immediately get feedback via color-coded markers to indicate which moves were successfully completed and which were missed. After completing a routine, reports provide detailed analyses indicating which segments are more challenging and which ones have improved since the last run.

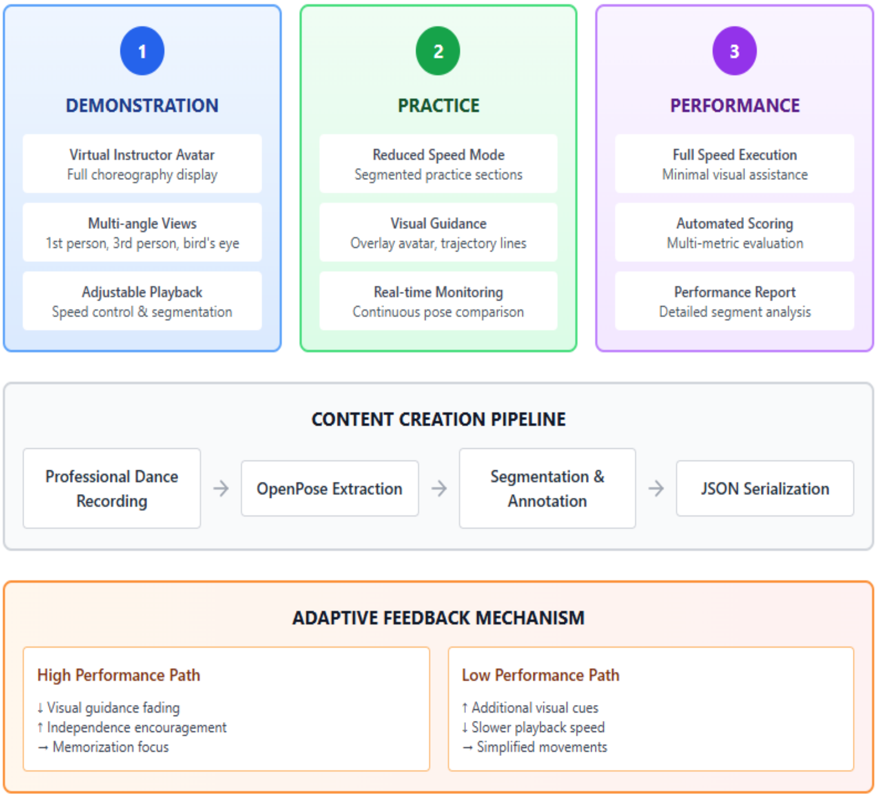

Figure 2. Interactive Learning Methodology Framework.

3.4. Designing Visual and Haptic Feedback

Good feedback systems are needed to orient users and maintain their interest while not overloading their cognitive capacity. The information layers are displayed by the visual feedback system, with the layering principle being "important and urgent information is at the first layer". The instructor avatar (bright colours, slight edge lighting very visible) is the principal direction giver [26]. Secondary cues are things like floor markers that tell you where to put your feet and arrows that direct you on where to go next. To prevent users from being too distracted by the main content, tertiary information such as beat indicators and score updates can be found in the peripheral vision.

The controller vibrates to give you time cues, and make you perform better. Beat pulses Beat pulses Beat pulses Beat pulses with the rhythm Beat pulses send soft vibration pulses on every musical beat, which make you stay in the rhythm even without looking at the screen. Movement verification haptics Upon differing from their goal positions, users receive brief tactile feedback to notify them that they have "moved out" successfully. The level of intensity of the haptic feedback varies from how much energy is needed to move. More vibrations mean strong movements, softer pulses mean lighter movements. The haptic system follows psychophysical considerations to ensure the feedback still easily understandable and not too tiring in the long term.

The difficulty level is adjusted in the feedback system according to the user's current performance. If users are consistently scoring high accuracy, the visual guidance gradually fades to encourage them to memorize the gestures and gain more independence. Meanwhile, users with difficulties in a particular section are provided with extra help, such as slower playback, more visual cues and simpler movement choices [27]. This type of adaptation retains a suitable challenge level for the users' own ZPD (zone of proximal development) and thus they are able to learn efficiently without becoming either bored or frustrated.

4. Findings and Discussion

4.1. Setup for the Experiment and Dataset

We ran a series of user studies to assess the dance VR system from different perspectives such as usability, immersion, instruction potential, and performance of the system. The study group consisted of 45 subjects (28 f, 17 m) with the age ranging between 18–45 years and was divided into three groups based on dance experience: novice (18 subjects), who had never taken dance lessons; intermediate (17 subjects), with 1–3 years of dance experience; and advanced (10 subjects), for those who had more than 4 years of dance experience. The contestants were split up into three groups, with each group competing in a different routine to a pop song about as difficult as: “Dynamite” by BTS, “Levitating” by Dua Lipa, and “Blinding Lights” by The Weeknd. Each dance sequence lasted 32 counts, i.e. about 30 seconds, and had a few common moves that are expected in pop dance, such as arm waves, body rolls, footwork sequences, and directions shifting.

There were a total of five sessions spanning across two weeks. In Session 1, participants were trained how to use the system and completed pre-assessment questionnaires to gauge their dance confidence and familiarity with VR, and their baseline dance performance was recorded. Participants were instructed to practice with the VR system (all the instructional features enabled) during sessions 2–4 for 30 min. Session 5: A final performance assessment level, post-experiment questionnaires such as the System Usability Scale (SUS), Presence Questionnaire (PQ), and Intrinsic Motivation Inventory (IMI), and semi-structured interviews.

4.2. System Performance Metrics

A technical performance assessment on key performance indicators for VR experience quality: latency, frame rate, tracking accuracy, and audio-visual synchronization. The mean system latency across all sessions was 16.3ms (SD=2.1ms), which is substantially below the 20ms limit suggested for motion sickness prevention. This is the latency of a user's motion and the corresponding visual feedback update. The frame rate remained at 90 frames per second, the same as the refresh rate of the Quest 2. We did notice a few dips to 88 frames per second when rendering several users at once, but that accounted for less than 0.5% of frames. These performance characteristic ensured the animation was fluid with no perceptible lag or judder.

Method We have verified the accuracy of motion tracking with laboratory tests involving 10 participants, by comparing the joint positions as recorded by our system with the ground truth provided by a Vicon motion capture system (8-camera setup, 200Hz). When only inverse kinematics was applied, the combination tracking method yielded a mean absolute error of 3.2 cm, 4.7 cm, and 8.4 cm for head position, hand positions, and estimated foot positions respectively. Adding Vive Trackers on the feet and hips reduced the error in foot position to 3.8 cm. This level of accuracy was sufficient to judge dance moves since the algorithms that compared the choreography were adjusted for individual body proportions and stylistic variances.

We leveraged human-annotated beat positions of the three songs to evaluate the performance of the audio analysis. The accuracy of the beat tracking was 94.7%, and the mean deviation between the detected and ground truth beat position was 18.2 ms. while the pacing changed throughout the making, the tempo estimation was fixed for each track, with a mean tempo standard deviation of 0.8BPM. This accuracy in timing helped visual signals and motion guides to be aligned with the music (this is necessary to keep a rhythm while working out).

4.3. Results for Usability and User Experience

The System Usability Scale of the standard confirmed that all the groups of participants were satisfied with the system. Descriptive statistics for item scores were calculated as a mean (standard deviation) of 78.4 (12.6) which is higher than the usual threshold of 68 that is considered as an indication of good usability. "Based on the experience-level statistics, it would seem that the system is rated slightly lower by advanced dancers (73.2) than by beginners (81.1) and intermediates (79.0)". This suggests that the finest dancers predicted more movement fidelity and complexity in the feedback. Descriptive analysis of the SUS components suggested that learning to use the system was easy (M=4.2/5) and that the system felt integrated with other systems (M=4.1/5). But it needs a little more customization options (3.3/5) and it should be a little less intimidating for VR novices (3.5/5).

For presence and immersion the Presence Questionnaire was used. It measures spatial presence, involvement and how real the experience was. Results showed that most of the participants experienced being "present" in the virtual dance floor (M=5.8/7, SD=0.9), 87 % of the participants agreed with the statement. Overall, the levels of spatial presence (M=6. 1/7) subscale scores were relatively high, indicating that the virtual dance studios are capable of making dancers feel like they were there. The high scores on involvement (M=5.7/7) suggested that the participants were very bored and were not interested in playing the game. These scores on the subscale measuring interest/ enjoyment remained high across all five practice sessions, indicating that the participants sustained their interest without any major fluctuations. The results of perceived competence were quite interesting in terms of trends. They were low at start for novices (session 2: M=3.8/7) but increased significantly by session 4 (M=5.4/7), indicating that the skills had been effectively acquired. The mean pressure/tension score was moderate (3.9 out of 7), suggesting that the situation was adequately challenging and not overly stressful. Qualitative comments highlighted enjoyment of practising in virtual environments, immediacy of feedback on performance and the ability to practise away from social scrutiny as key motivational elements.

4.4. How well you learn and how well you do at work

What remained to be seen was how much the dance performances in the first session (baseline) and the final session (final) rated by three blind expert evaluators independent of each other had improved. The combination of the accuracy, timing and style separated measures into a single score showed a large improvement in all the participants groups. The average score improved from 3.8 out of 10 in the beginning to 6.7 out of 10 in the end, which is a 76% improvement. Paired t-tests confirmed statistically significant differences ($t(44) = 14.2$, $p<0.001$, Cohen's $d=2.1$), indicating a large effect.

A level-based analysis revealed different learning curves. Novices experienced the largest absolute improvements increasing from 2.9/10 to 6.2/10 (114% improvement), indicating that the system is suitable for novice dancers. Intermediate dancers improved 67% from 4.2/10 to 7.0/10, and advanced dancers improved 40% from 5.2/10 to 7.3/10. These trends indicate that the system appears to work best for the complete novice, although all groups demonstrated significant improvement. The relatively smaller improvement for the advanced dancers could be explained by ceiling effects and the fact that relatively simple choreography was used in the study.

A detailed analysis of the dimensions of performance revealed that timing/rhythm was the dimension that improved most (80.6%), followed by movement style (78.9%), and by positional accuracy (74.4%), as shown in Figure 3. Such trend suggests that real-time beat indicators and rhythm guidance procedures of the system could effectively facilitate the temporal coordinating ability ' [s] of the users. Style results demonstrate that viewing the instructor avatar and receiving feedback on quality of movement did in fact transmit aspects of performance at a level deeper than simply mimicking the choreography. The predicted (slight) additional benefit in positional accuracy might reflect inherent difficulties in spatial learning and/or a limit to track precision in describing complex body postures.

We assessed for retention of learning by conducting follow-up performance tests at 1 week after the final training session in the absence of practice. A substantial 84% of the acquired skills were retained by the subjects, whose mean performance scores were 5.6/10 at the retention session and 6.7/10 at the completion of trainings. The high retention rate indicates that the VR training taught a more long-term learning experience instead of immediate learning gains. Interestingly, novices showed a slightly better retention rate (88%) than expert dancers (78%). "Maybe it's because the more novice group learned more fundamental movement patterns, and those are less likely to go away."

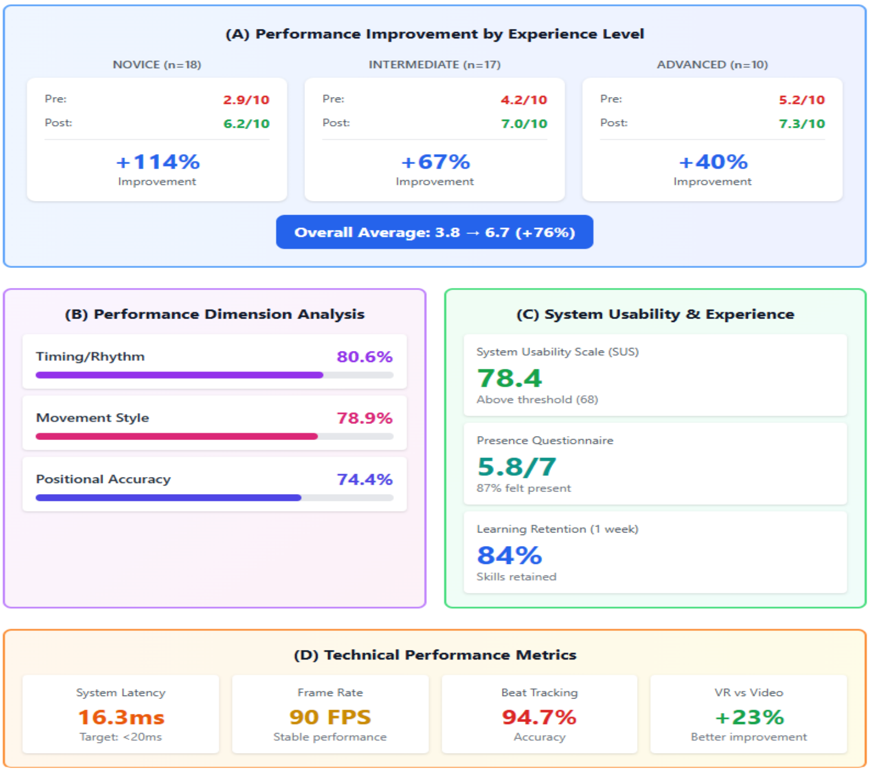

Figure 3. Experimental Results Summary.

4.5. Limitations and Comparative Analysis

There was a control group of an additional 20 individuals who learned the same choreography via standard online video tutorials for an equivalent amount of practice time. This contrast is not in the primary VR experiment, but it does allow us to observe how effective the VR system is. Those who did use VR increased their total performance score by 23% more than those with video tutorials (76.3% vs. 53.1% improvement). Statistical analysis confirmed that results from VR training were significantly superior (independent t-test: t (63)=3.8, p<0.001). Participants in VR also said that they had more fun (6.3 vs. 4.8/7) and were more confident that they could do the choreography (5.9 vs 4.3/7).

A couple of things to keep in mind when reading these findings. The investigation was based on comparatively simple pop choreography which is 30 seconds long, so it's still up in the air whether the approach will pan out for lengthy or intricate sequences. Due to the limitation of tracking accuracy, particularly for lower body motion, in conjunction with IK estimation, the quality of system feedback as well as the accuracy of performance assessment might be compromised. Although the sample was mixed regarding dance experience, it primarily consisted of young adults with a high level of physical fitness and technical competency, which could limit generalizability to older adults or individuals with mobility impairments. The two-week study period represents short-term learning; however, further research is required to investigate long-term skill acquisition and retention.

Technical limitations include the fact that stand-alone VR headsets have less processing power, which resulted in the environment being less detailed and the avatars looking worse. Network latency also made real-time multiplayer features impossible to implement, which might have added more to the social learning element. It takes a lot of work from dance professionals and technical staff to make the content creation pipeline work that could make it harder to grow. A few dreamers said that they are a little uncomfortable for long periods, indicating that more ergonomic and fatigue-mitigating features are needed. Future investigation should address these limitations through technological advancements, extended longitudinal designs, as well as by exploring other user populations and choreographic approaches.

5. Conclusion

We describe the planning, execution, and evaluation of a full-scale VR pop music and dance system for the provision of entertaining education in the home. The result was a system that integrated mobility tracking, audio analysis, the provision of interactive tutorials, and adaptive feedback in a way that was fun and effective for learning to dance. The results prove with actual data that VR-based dance teaching is far superior to video-based dance teaching. In the end everyone had increased their overall dance regimen by 76% after just four 30-minute performance sessions, with timing and movement style being the areas in which they had improved THE most. The system was best for complete novices who saw their performance more than double. The high ratings for enjoyment and motivation, together with the fact that the students remained engaged at the start of several sessions, imply that the VR solution overcomes typical issues in remote dance tuition, for example, lack of individualized feedback, lack of awareness of one's surroundings. The influence of this work is not limited to the specific instantiation, but can be generalized to the broader context of VR music and movement apps. The modular architecture of our system and the content pipeline, may be useful as templates for other performing arts applications, fitness, or rehabilitation applications. The results on effective visual guidance strategies, haptic feedback design, and adaptive difficulty adjustment lead the guidance in embodied creation of VR experiences.

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