Journal of Integrated Arts Education
https://journals.bilpubgroup.com/index.php/jiae

ARTICLE

The Paradox and Promise of Virtual Reality in Dance Movement Learning: Meta-Analysis

Yi Zhu

School of Arts, Nanjing University, Nanjing 210093, China

ABSTRACT

Although the effectiveness of training motor skills in virtual environments has been validated, its impact within the arts, particularly in higher dance education, remains inconclusive. The present study conducted a meta-analysis to assess the impact of virtual reality (VR) technology on university-level dance movement learning. The results show that while VR demonstrates positive effects in enhancing the visualization of movement amplitude, its influence on movement coordination and force expression is inconsistent, with evidence of negative transfer effects. Subgroup analyses reveal that VR is particularly effective in improving movement coordination and force control, but less so for movement amplitude. Furthermore, high heterogeneity and publication bias among small-sample studies suggest variability in design and implementation across contexts. In addition, the study further explores the inherent paradoxes between virtual technology and dance education, addressing the challenge of seeking authentic artistic experiences within fully virtualized environments. The findings suggest that while VR offers new possibilities for movement visualization and feedback, it often lacks the emotional and somatic depth essential to dance. The study emphasizes the importance of balancing technological standardization with creative expression and proposes pedagogical strategies that leverage VR as a complementary rather than a substitutive tool. This research contributes to the evidence base for arts-based digital learning and offers practical guidance for integrating immersive technologies into contemporary dance curricula..

Keywords: VR; Higher Education; Dance Movement Learning; Instructional Visualization

*CORRESPONDING AUTHOR:
Yi Zhu, School of Arts, Nanjing University, Nanjing 210093, China; Email: 502022190024@smail.nju.edu.cn

ARTICLE INFO
Received: 24 April 2025 | Revised: 19 May 2025 | Accepted: 22 May 2025 | Published Online: 5 June 2025
DOI: https://doi.org/10.30564/jiae.v1i1.9515

CITATION
Zhu, Y., 2024. The Paradox and Promise of Virtual Reality in Dance Movement Learning: Meta-Analysis. Journal of Integrated Arts Education. 1(1): 1–13. DOI: https://doi.org/10.30564/jiae.v1i1.9515

1. Introduction

In recent years, the use of virtual reality (VR) technology as a tool for training and education has seen significant advancement. The application of VR in dance education has, to some extent, broken through the limitations of traditional top-down instructional methods, as well as the constraints of time, space, and physical proximity in conventional dance classes. VR introduces immersion, visualization, and interactivity into the dance learning environment [1], and its use as a learning mechanism offers greater benefits than simple video playback [2]. On one hand, in the context of visualization-based dance instruction, VR enables the recording of movement trajectories, helping students gain a clearer and more intuitive understanding of the technical details involved in performing dance movements. For example, VR technology can be used to assess a dancer's arm positioning [3], or to calculate the distance between teacher and student movements using dynamic time warping (DTW) combined with Euclidean distances between joint angles, positions, and orientations [4]. On the other hand, VR can also provide learners with real-time visual feedback about their body positioning, timing deviations, and differences between actual and expected movements in a three-dimensional space [5], thereby helping students improve movement accuracy.

However, Aspasia (2021) questions the presumed positive effects of technology in education, suggesting that when applied to dance instruction, the impact on students may be negligible or only moderate [6]. Although the effectiveness of training motor skills in virtual environments has been empirically supported [7], there is still no definitive conclusion regarding its impact in the domain of dance [8]. Some studies have shown that the biological motion information provided through VR feedback tends to be abstract and decontextualized for learners, making it difficult to interpret effectively in a way that reduces performance errors [9]. Moreover, this approach does not necessarily offer greater learning advantages than simple observational imitation [10].

Currently, the technologies and pedagogical knowledge developed specifically for VR-based instructional environments remain limited [11], with only a small number of research projects having made progress in using VR as a medium for dance education [1,2]. Moreover, the integration of VR into dance education often relies heavily on additional motion capture systems, such as suits used in conjunction with camera-based tracking technologies [3,4]. While several studies support the potential of VR to enhance dance instruction [3,4], few have specifically examined whether these technologies effectively support the cognitive processes involved in learning through movement visualization [5]. The lack of such evidence-based evaluations limits the practical implications of VR-enhanced visualized movement instruction and continues to hinder the broader implementation of VR technologies in dance education [1].

Hargreaves' concept of evidence-based education advocates that educational research should be conducted like medical science, focusing on "what works" in practice. The aim is to provide educators with robust empirical evidence regarding the effectiveness of instructional strategies, thereby improving teaching quality and informing professional decision-making [6,7]. Meta-analysis, as a foundational method of evidence-based practice, is essential for synthesizing findings from multiple studies and generating generalizable conclusions [8]. To provide updated evidence for the application of VR in dance education, this study adopts a systematic review and meta-analytic approach. Guided by the PICOS framework, the central research question is: What is the effect of VR (I), compared with traditional teaching methods (C), on improving students' dance learning outcomes (O), particularly among university-level dance majors (P)? This question is addressed through a structured synthesis of existing empirical studies (S) to offer practical insights and decision-making support for dance education professionals.

2. Method

2.1. Literature Search

This study followed the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to minimize bias and enhance the rigor of the review process [9]. According to PRISMA recommendations, systematic reviews should include literature from at least three independent databases to ensure comprehensiveness and objectivity in data collection [10]. Drawing on methodological strategies from existing systematic reviews and meta-analyses in the field of educational technology [10,11], this study selected four English-language database: EBSCO, Ei Compendex, IEEE Xplore Digital Library, Web of Science, as well as the Chinese-language CNKI. These databases collectively cover a wide range of high-impact journals in education and ensure that the included studies meet quality standards required for evidence-based synthesis. Other platforms, such as Google Scholar, ResearchGate, and JSTOR, were excluded due to the lack of rigorous quality control and limited advanced search functionalities [12]. Moreover, the inclusion and peer-review status of the publications found in these sources is often unclear. Previous studies have also indicated that articles from these platforms are typically already indexed in the primary academic databases mentioned above [11]. Therefore, the selected five databases are considered sufficient to meet the standard requirements for conducting a systematic review and meta-analysis.

2.2. Study Screening

This review established a set of eligibility criteria (see **Table 1**). Given that randomized controlled trials (RCTs) are widely regarded as the gold standard in experimental research for evaluating the effectiveness of interventions, due to their high level of internal validity, this study included only RCTs as part of its inclusion criteria. Moreover, in dance education, student performance is typically assessed using summative evaluations, which are designed to capture the breadth of knowledge and skills acquired during training [13]. Among these, the most used summative assessment is the dance movement performance score. Therefore, eligible studies were required to report quantitative outcome data related to students' dance movement learning, such as movement accuracy, amplitude, timing, or coordination.

Table 1. Inclusion criteria.

Category	Inclusion
Topic relevance	① The study must focus on the application of VR in dance learning, specifically examining its impact on dance movement acquisition among university-level dance students. ② VR must be the central subject of the research. Studies where VR is only briefly mentioned or serves as a minor aspect of the research will be excluded. ③ The study must include a comparison between VR-based and traditional dance teaching methods. ④ The study must report quantitative outcome data related to students' acquisition of dance movement. ⑤ The study must be a randomized controlled trial (RCT) with a clear description of research design, sample size, data collection, and analysis methods. ⑥ Preference is given to studies published within the last ten years to ensure relevance to current technology and educational practices.
Study quality	① The study must be peer-reviewed and published in a recognized academic journal or conference proceedings. ② The full text must be accessible and retrievable from authoritative academic databases. ③ The publication must include complete methodological and reporting information. ④ Excludes: opinion pieces, editorials, literature reviews, abstracts, posters, and non-peer-reviewed reports.

2.3. Data Extraction

The data extraction process focused on collecting the following key information from each eligible study:

1. Study identification: including article title, authors, journal or conference name, and year of publication.
2. Sample characteristics: number of participants and demographic details (e.g., age, gender).
3. Study design: description of the specific application of VR technology in the intervention.
4. Intervention duration: length and frequency of the VR-based instructional program.
5. Comparison condition: details regarding the control group or alternative teaching method used for comparison.
6. Primary outcome measures: students' performance in acquiring dance movements, such as accuracy, amplitude, coordination, or timing.
7. Secondary outcome measures: any reported indicators related to student satisfaction, self-efficacy, or changes in learning attitudes.

2.4. Risk of Bias Assessment

This study used the Cochrane Collaboration's Risk of Bias tool and the GRADE (Grading of Recommendations Assessment, Development and Evaluation) framework to assess the overall quality of evidence. The GRADE framework classifies evidence into four levels based on its quality: high-quality evidence (Grade A) is denoted as "++++" indicating that further research is unlikely to change the current effect estimate; moderate-quality evidence (Grade B) is denoted as "+++" indicating that further research may significantly impact the results, possibly changing the current effect estimate [14]. In this study, all included studies had good evidence quality, suggesting that the research findings are relatively reliable.

2.5. Statistical Analysis Methods

All statistical analyses were conducted using RevMan 5.4, following the Cochrane Handbook for Systematic Reviews of Interventions. A random-effects model was employed to account for the potential heterogeneity across studies.

For continuous outcomes, the effect size was calculated using the Mean Difference (MD) or Standardized Mean Difference (SMD) with 95% confidence intervals (CIs), depending on the measurement scales of the included studies.

Statistical heterogeneity was assessed using the I^2 statistic and the Chi^2 test. I^2 values of 25%, 50%, and 75% were interpreted as low, moderate, and high heterogeneity, respectively. In cases of high heterogeneity ($I^2 > 75\%$), sensitivity analyses were conducted by removing outlier studies to examine the robustness of the pooled results.

Publication bias was examined using Egger's regression test.

3. Results

3.1. Literature Search Results

A total of 774 records were initially retrieved from the five selected databases through advanced search strategies. After removing duplicates (n = 32) and retracted publications (n = 12), 730 studies remained. Title and abstract screening resulted in the exclusion of clearly irrelevant articles, leaving 77 potentially eligible papers. The full texts of these studies were then reviewed to determine their final inclusion based on the predefined criteria. As a result, 5 studies were retained for inclusion in this systematic review and meta-analysis. A detailed overview of the screening process is presented in **Figure 1**. The specific characteristics of the included studies are presented in **Table 2**.

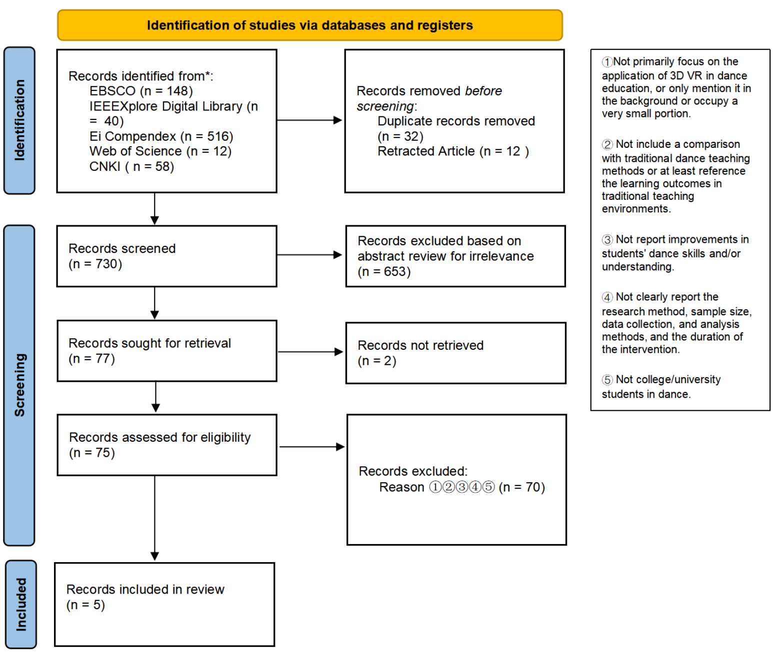

Figure 1. PRISMA flow.

Table 2. Characteristics of included studies.

Authors	Year	Duration	Sample Size (T/C)	Dance Type	Outcomes
Zhang N.	2022	/	10/10	Folk dance	①
Abraham A.	2019	3Days	33/33	Classical ballet	①
Liu Min	2022	60 Days	30/30	/	①②③④
Chen Y.H.	2024	16 Hours	40/40	/	①②③④
Zhou Y.H.	2021	30 Days	5/5	/	①

Note: T = Experimental group; C = Control group.

Outcome Measures: ① Movement mastery; ② Movement amplitude; ③ Movement force; ④ Movement coordination.

3.2. Meta-Analysis Result

The study used a random-effects model to conduct a meta-analysis of the impact of VR interventions on students' dance movement performance (**Figure 2**). A total of 9 studies were included, with a pooled effect size of MD = 4.76, 95% CI = [1.19, 8.32], $Z = 2.61$, $p = 0.009$, indicating that the experimental group performed significantly better than the control group in dance movement performance, with statistical significance. According to Cohen's criteria for effect size interpretation [15], this result reflects a large effect of VR on dance movement learning outcomes. The heterogeneity test showed $Tau^2 = 34.98$, $Chi^2 = 279.46$, $df = 11$, $p < 0.00001$, $I^2 = 96\%$, suggesting a high degree of heterogeneity among the studies, indicating substantial variation in effect sizes across the studies.

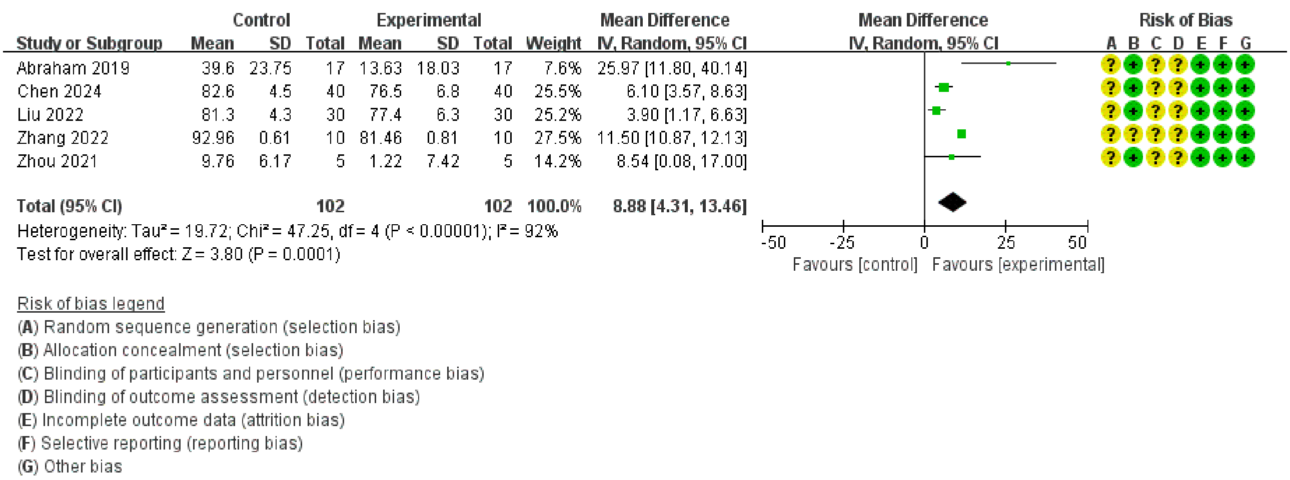

Figure 2. Overall effect of VR on dance movement performance.

3.3. Sensitivity Analysis

The results of the sensitivity analysis (see **Table 3**) indicate that after removing the Zhang 2022 study, heterogeneity significantly decreased, with I^2 dropping from 92% to 79%. However, the overall effect still supports the experimental group, showing that VR intervention continues to have a significant positive impact on students' dance movement performance, with the experimental group outperforming the control group.

Table 3. Sensitivity analysis.

Study	Tau^2	Chi^2	*df*	*p*	ES	95%CI	I^2
Abraham 2019	34.51	273.93	10	< 0.001	3.92	[0.31, 7.53]	96%
Chen 2024	31.61	230.78	10	< 0.001	5.28	[1.71, 8.85]	96%
Chen 2024	36.21	261.10	10	< 0.001	4.95	[1.15, 8.74]	96%
Chen 2024	38.96	274.33	10	< 0.001	4.68	[0.75, 8.61]	96%
Chen 2024	35.25	255.29	10	< 0.001	5.03	[1.28, 8.78]	96%
Chen 2024	38.96	274.33	10	< 0.001	4.68	[0.75, 8.61]	96%
Liu 2022	28.91	211.47	10	< 0.001	5.41	[1.98, 8.84]	95%
Liu 2022	37.01	265.78	10	< 0.001	4.87	[0.08, 8.71]	96%
Liu 2022	36.75	266.61	10	< 0.001	4.88	[1.05, 8.70]	96%
Liu 2022	36.03	264.19	10	< 0.001	4.94	[1.16, 8.73]	96%
Zhang 2022	9.35	48.32	10	< 0.001	3.39	[1.26, 5.53]	79%
Zhou 2021	35.48	279.45	10	< 0.001	4.51	[0.81, 8.22]	96%

3.4. Sub-Group Analysis

In the analysis of the "movement amplitude" subgroup, there was no significant difference between the experimental and control groups. The experimental group showed a slightly lower movement amplitude compared to the control group, but the effect size was negative, and the 95% confidence interval included zero, indicating no statistically significant difference. At the same time, the results of the heterogeneity test showed consistency across studies, with very low heterogeneity ($I^2 = 0\%$) and a p of 0.41, suggesting no significant between-study variation. Therefore, it can be concluded that VR intervention did not show significant improvement in movement amplitude.

In the "movement coordination" subgroup analysis, the experimental group performed significantly better than the control group, demonstrating improved movement coordination. The effect size was 3.39, and the 95% confidence interval did not include zero, indicating a statistically significant improvement in movement coordination for the experimental group. The heterogeneity test showed good consistency across the studies ($I^2 = 0\%$) with a p of 0.69, meaning the results were stable, and there was no significant heterogeneity. Therefore, it can be concluded that VR intervention significantly improves movement coordination.

In the "force control" subgroup analysis (**Figure 3**), the experimental group also showed a clear advantage. The effect size was 2.46, and the 95% confidence interval did not include zero, indicating a significant improvement in force control for the experimental group. The heterogeneity test showed good consistency across studies ($I^2 = 0\%$), and $p = 0.64$, indicating good stability of the results. Therefore, VR intervention also has a significant effect in improving force control.

3.5. Egger's Test

In the preliminary analysis, Egger's test showed significant publication bias ($t = -3.49$, $p = 0.0059$), suggesting the possible presence of small study effects or other sources of bias (see **Table 3**). After excluding the small sample studies, the result of Egger's test was no longer significant ($t = 1.02$, $p = 0.3393$), indicating that the publication bias was mainly driven by the small sample studies (see **Table 4**). Small sample studies, due to their lower statistical power, are more susceptible to random errors and publication bias, which can lead to false positive results or overestimated effect sizes. Additionally, sensitivity analysis showed that after excluding small sample studies, heterogeneity significantly decreased (Tau^2 decreased from 12.6145 to 5.1669), further supporting the robustness of the findings. Therefore, excluding small sample studies helps reduce bias and improve the scientific rigor of the meta-analysis.

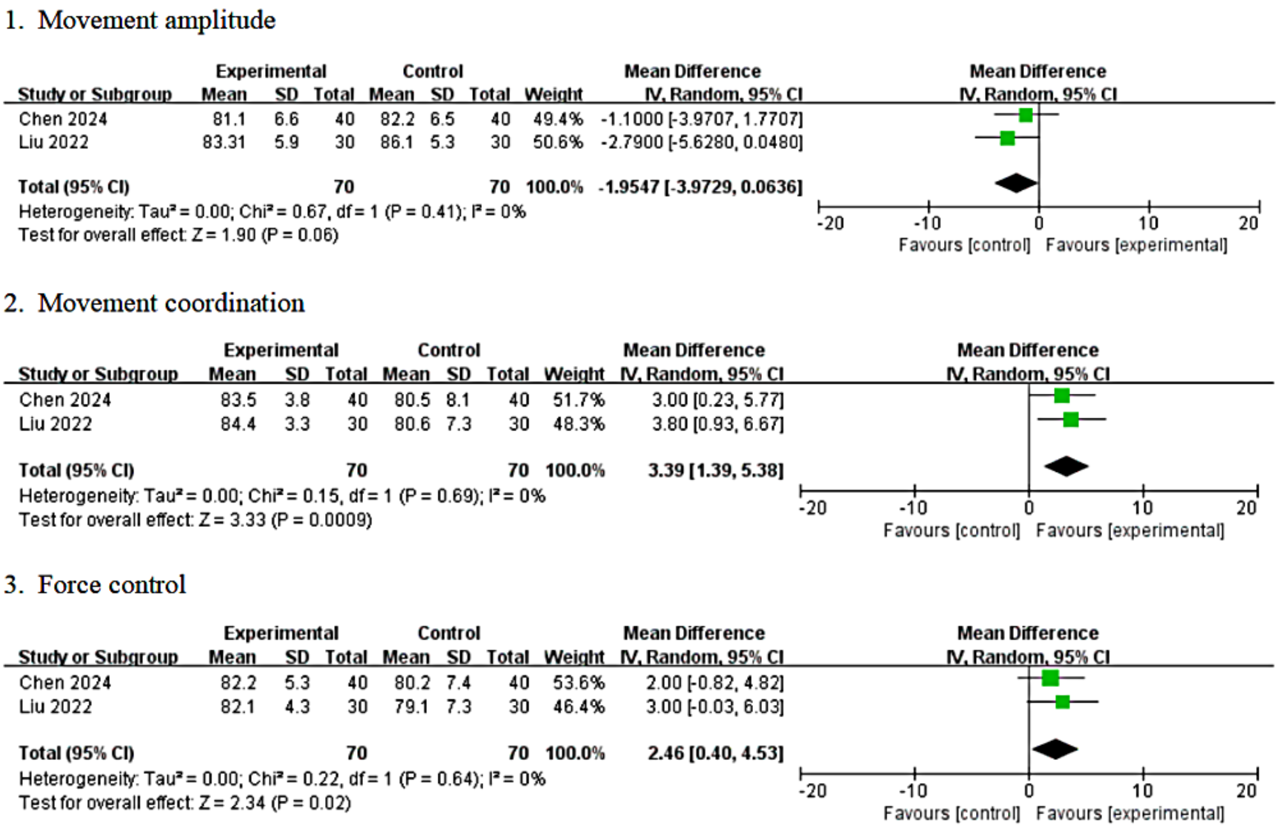

Figure 3. Sub-group analysis.

Table 4. Egger's test.

	t	*df*	*p*	Bias Estimate	Tau^2
Including all studies	-3.49	10	0.0059	-5.2998 (SE = 1.5202)	12.6145
Excluding small sample studies	1.02	8	0.3393	2.8109 (SE = 2.7662)	5.1669

4. Discussion

4.1. VR Empowering Dance Education

Although the meta-analysis results showed no statistically significant improvement in movement amplitude, prior research and technical models suggest that VR holds unique potential in enhancing this dimension [16]. For example, the "Controlling the Human Body" model has long been a key research direction in VR development [17]. This model uses sensors to directly capture body position data, which is then used to simulate and reproduce human movements. Because these parameters closely reflect real bodily motions, the model facilitates accurate re-creation of movement patterns, offering learners important visual references. This allows students to more clearly understand and internalize the expected amplitude of movement and to visually compare the differences between their motions and the standard, thereby accelerating the learning process and improving performance. Compared to traditional dance classrooms, this model offers more effective support for students seeking to master movement amplitude. Additionally, the feature plane similarity-based posture analysis method compares key points or specific body part characteristics to perform pose estimation and analysis [4]. Like the human body control model, this method can automatically detect, recognize, and evaluate movement and posture. Its advantage lies in its ability to construct efficient similarity-matching mechanisms [4], enabling stable and accurate assessment of pose variation. When applied to dance visualization, this method not only supports reliable movement analysis but also helps learners identify discrepancies between their movements and the standard, particularly in terms of movement amplitude, facilitating timely correction and improvement.

However, limitations remain in the use of VR. Time delay and yaw deviation are two common issues. For example, if a student's orientation differs slightly from the instructor's, yaw errors may occur, introducing unwanted discrepancies in motion data [18]. In such cases, even a student's well-executed movement may be inaccurately reflected in the feedback. These technical challenges may help explain why VR-based instruction is less effective for enhancing movement force and coordination. Results from the current meta-analysis further support this finding, showing the limited impact of VR on training these two dimensions. In contrast, traditional dance instruction appears to be more effective in developing forceful and coordinated movement execution.

VR can provide both virtual practice environments and virtual instruction [19]. Regardless of its form, the goal of VR applications in education is to facilitate the transfer of learning from simulated environments to real-world tasks. However, intuitively designed VR training environments do not always benefit motor learning, nor do they consistently promote the successful transfer of skills to real-life settings [19]. Computer-mediated environments with audiovisual feedback may not produce positive transfer effects and, in some cases, may even lead to negative transfer [20–22]. This helps explain the limited effectiveness of VR in enhancing movement force and coordination in dance movement visualization. On one hand, discrepancies between virtual and real-world tasks contribute to negative transfer. These differences often arise due to the simplified nature of tasks in virtual settings [19]. For instance, in both Chen and Zhang (2024) [23] and Liu (2022) [4], motion capture systems were used to create 3D dance animations, which students viewed before practicing in a controlled laboratory environment. However, this type of VR-based learning was relatively surface-level, with learning objectives focused primarily on limb movement replication. In contrast, traditional dance instruction incorporates not only physical movements but also elements such as breath control, mind-body coordination, and expressive nuances [24]. While 3D animations can visualize aspects like movement trajectory, timing, joint angles, and body positions, they cannot replicate the subtle embodied dimensions that are essential to holistic dance training. As a result, students learning in VR environments are more susceptible to negative transfer. Moreover, although kinematic data has been proven effective in distinguishing emotional expression in dance [25], it has not been meaningfully applied to practical teaching but remains in the domain of technical emotion recognition research.

On the other hand, instructional dynamics in VR differ from those in real-world dance training [19]. In both experiments by Chen and Zhang (2024) [23] and Liu (2022) [4], students were tasked with replicating preset dance movements. Real-time feedback was provided via sensors and computer playback to help correct technical errors. However, such systems often limit students to practicing predefined choreography, restricting their ability to adjust movements based on personal skills or stylistic expression. This overly standardized "academic" approach to dance education overlooks the cultural and creative dimensions of movement. Historically, many landmark developments in dance stemmed from breaking traditional norms, such as the early 20th-century modern dance movement that sought freedom from classical ballet's rigid conventions. Dance education must, therefore, support individuality and innovation. In VR-enhanced dance visualization, students should not be limited to rote learning of standard movements; they should be encouraged to adapt, reinterpret, and create through VR tools. The goal should be not only to master existing techniques but also to challenge and extend them. In contrast, traditional classroom dynamics often emphasize a more holistic and flexible understanding of dance. Teachers introduce the technical fundamentals, followed by imitation, repetition, and recombination in diverse dance contexts. They guide students to analyze rhythm, musicality, emotion, and cultural narratives, enabling them to adjust speed, force, and expressive style to fit the artistic intent. Such dynamic instruction fosters not only technical mastery but also the transferability and creative application of learned skills, ultimately enhancing both competence and artistic depth.

4.2. The Paradox of VR and Dance Education

Dance—as an art form deeply rooted in embodied sensation and physical interaction—inevitably encounters a fundamental tension when integrated with the digitally programmed world of VR. The fusion of these two domains carries a built-in paradox: users know the environment is virtual, and yet their senses may convincingly perceive it as real [26]. Embodied learning and memory are cultivated through repeated physical practice and somatic feedback [27]. While virtual environments can simulate visual and auditory feedback, they struggle to reproduce tactile and muscular sensations. As a result, the muscle memory developed through VR-based training may not translate seamlessly into real-world performance [28], leading to a disconnect between bodily perception and actual execution. Furthermore, technology is not merely a tool—it also shapes how we experience and interpret the world [29,30]. Learning dance in a virtual context may lead to overreliance on programmed sequences and algorithms, potentially undermining the essence of dance as a spontaneous and expressive art form. Much of the aesthetic authenticity of dance arises from its real-time interaction with space, with others, and with music [31], all of which are difficult to fully replicate within a strictly programmed VR setting.

This raises a critical question: How can we pursue authentic artistic experience within fully virtualized environments? This challenge extends across multiple dimensions, including the adaptability of the technology, the preservation of artistic integrity, the engagement of audiences, and the transmission of cultural meaning.

First and foremost, technological adaptability serves as the foundation. Virtualization technologies, particularly VR and augmented reality (AR), must be sufficiently flexible to accommodate diverse artistic forms and modes of expression. This requires technical solutions that can accurately simulate dynamic elements in dance, such as rhythm and bodily expression. Moreover, VR should enable artists to explore new methods of creation unconstrained by physical limitations, thereby expanding the expressive capacity and innovativeness of their work. Secondly, it is essential to preserve the core of art. In virtual environments, maintaining the emotional depth and expressive resonance of artistic works is critical [30]. The goal is not merely to replicate real-world artistic experiences but to capture those deeply affective and aesthetic dimensions that move audiences. Recent studies have shown that VR environments can effectively elicit emotional responses through immersive and interactive design [32], suggesting their potential to convey the emotional essence of dance. Preserving the essence of art involves conveying its emotional and philosophical depth, ensuring that even within fully virtual contexts, artistic works can resonate meaningfully with viewers. Research shows that when teaching dance through virtual platforms, educators must not only impart technical knowledge and movement skills but also teach students how to interpret and embody emotional content in dance [33]. To achieve this, instructors can adopt several strategies.

Firstly, enhancing emotional engagement by increasing interaction within the VR environment—for example, simulating audience feedback or co-performer interaction, which can help students experience the tension and passion of live performance.

Secondly, providing rich expressive tools to ensure that even subtle movements are captured and reproduced with high fidelity, enabling accurate transmission of emotional nuance.

However, it is crucial to recognize that the essence of dance lies not in technical precision alone but in the dancer's ability to communicate emotion and narrative through movement. Every dancer possesses a unique physique, movement habit, and expressive style—personal characteristics that play a pivotal role in dance performance. Excessive reliance on VR to enforce standardization may suppress individual expression, thereby diminishing dance's artistic impact. A balanced approach is needed—one that prioritizes personalized learning and encourages students to explore and express their dance language.

Thirdly, dance curricula built on virtual technology should also include deeper explorations of the stories and cultural meanings embedded within choreographic works. This can be achieved through educational VR content, such as interactive commentary or cultural background modules, allowing students to understand not just the physical technique but also the historical and philosophical context of the dance they are learning.

In addition, audience engagement is a key metric for evaluating the success of an artistic experience. In virtualized environments, engagement goes beyond interactivity with the interface, it involves the viewer's emotional and intellectual connection with the artwork. Therefore, developing highly interactive interfaces and participation mechanisms is vital. For example, VR-based dance performances can be designed to allow audience members to choose their perspective or influence the sequence of events, making each experience unique. This kind of participatory design enhances immersion and invites the audience to discover layered meanings through active exploration—something that traditional viewing modes often fail to offer. Lastly, cultural transmission is indispensable in virtual artistic experiences. Art is deeply embedded in cultural contexts, and any attempt to present or teach art virtually must faithfully convey the cultural roots and meanings it embodies. This involves not only reproducing the external form of the work but also communicating the sociocultural background that informs it. In virtual dance education, for instance, instruction should go beyond teaching steps to include the history, philosophy, and social relevance of the dance form. Through augmented reality tools, rich cultural annotations and historical narratives can be embedded into the virtual classroom, enabling students to appreciate the full artistic and cultural value of the dance as they learn.

In summary, authentic artistic experience in virtual settings is not merely about sensory immersion, it depends on emotional and intellectual resonance. VR offers new avenues for exploring and experiencing art, but the authenticity of this experience relies on the synergy between technological adaptability, the preservation of artistic depth, active audience participation, and a profound understanding of cultural context.

4.3. Reframing Evaluation Objectives in Technology-Enhanced Dance Education

As technology continues to evolve, we must ask: do our evaluation standards need to evolve as well? In current research on technology-enabled dance education, traditional evaluation criteria are still predominantly employed [4,22]. However, when technology becomes integral to dance education, the focus must shift beyond technical proficiency toward assessing students' ability to creatively engage with and through technology. This paradigm shift calls for rethinking how we evaluate student growth and development in the artistic domain, how we understand their performance in a more holistic and meaningful way.

Second, we must be cautious of the risk of mechanized learning in VR-based dance education. Although virtual environments may appear to offer ideal learning platforms, they may inadvertently induce students to fixate on technical precision, sidelining the unique kinesthetic and expressive nature of dance as an art form. The application of technology must guide students not only toward technical excellence but also toward breakthroughs in emotional expression and artistic sensitivity. Only then can students truly appreciate the essence of dance, rather than fall into the monotony of rote, mechanical repetition.

Therefore, it is necessary to design virtual learning environments that are truly suited to the nature of dance. This includes attention to the portability and practicality of hardware. Since dance is fundamentally a form of bodily perception and dynamic expression, students must be free to move and perform within a physical space. Lightweight and user-friendly devices are essential for capturing movement and providing real-time feedback. In parallel, designers must consider the practical needs and accessibility for learners. If the technology is cumbersome or inaccessible, it creates barriers rather than enabling tools. A functional virtual learning space must be both inclusive and supportive, offering students rich and flexible learning experiences.

Moreover, the design of virtual learning tasks must reflect the dynamics of real-world dance training. This alignment is crucial for facilitating positive transfer of learning. Tasks should mirror authentic choreographic and performance challenges, allowing learners to apply what they've practiced in immersive settings to real artistic contexts.

In conclusion, VR in dance education is not merely a technological intervention—it represents a transformation of educational philosophy. It challenges us to reexamine the purpose and values of dance education itself. We must move beyond the goal of technical mastery to cultivate students' ability to apply technology flexibly, to think critically, and to innovate creatively. This approach fosters a new kind of productive force in the dance field, one that merges tradition with innovation, embodiment with imagination. Only through this integrated vision can we realize the true value of dance education in the digital era.

5. Limitation

Although this study systematically synthesized evidence on the effects of VR interventions in dance movement learning through comprehensive literature search and meta-analysis, several limitations remain. First, the number of included studies was limited, and some had small sample sizes, which may affect the stability of the overall effect size. Second, the primary analysis revealed substantial overall heterogeneity, indicating variation across studies in terms of intervention types, participant characteristics, or measurement tools. However, it is worth noting that after subgroup analyses by outcome dimensions, heterogeneity significantly decreased ($I^2 = 0\%$), suggesting that the observed heterogeneity primarily stemmed from mixed outcome indicators rather than inconsistencies in the data itself. This highlights the importance of analyzing different movement dimensions separately. In addition, publication bias tests indicated a potential overestimation of effects in small-sample studies. Nevertheless, sensitivity analysis showed that the positive effects of VR interventions remained significant even after excluding these studies, which strengthens the robustness of the conclusions.

Overall, although the current evidence base is still developing, this study adopted rigorous inclusion criteria and quality appraisal methods, and most notably conducted a novel dimension-specific analysis of VR's impact on dance movement learning. This provides both directional evidence and empirical foundations for the future integration of educational technology and dance training.

6. Conclusions

This study is the first to conduct a dimension-specific subgroup analysis of VR intervention effects in dance movement learning, examining movement mastery, movement amplitude, coordination, and force control. The results revealed significant advantages of VR in improving "movement coordination" and "force control," while its effect on enhancing "movement amplitude" was not statistically significant. These differentiated findings offer practical insights for the targeted design of future VR training programs and provide theoretical support for addressing issues of heterogeneity in related research.

At the technical level, this study incorporated current advances in VR such as motion capture, 3D posture reconstruction, and human-computer interaction recognition—in the context of dance education. It further explored the advantages and limitations of VR interventions in transmitting fine motor information, establishing body mapping, and enabling sensory feedback. The study also identified the risk and underlying causes of "negative transfer effects" in current VR-based training. This integrative perspective, which combines educational technology with the psychological mechanisms of physical learning, broadens the research paradigm of VR applications.

In sum, this study not only provides a systematic synthesis of current evidence but also offers theoretical and empirical support for optimizing the technical pathways and pedagogical strategies of VR-based dance education. It contributes valuable references for the development of future integrated models of dance learning.

Funding

Not applicable.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

No new data were created.

Acknowledgments

The author would like to thank Dr. Xinyu Dou, PhD, Faculty of Education, The University of Hong Kong, for her valuable methodological guidance during the data analysis process, as well as her constructive suggestions on revising the figures and responding to reviewers' comments. Her expertise and support have significantly improved the quality and clarity of the manuscript.

Conflicts of Interest

The author declare no conflict of interest.

Reference

[1] Liu, L., Sun, H.J., 2014. The application and dance design requirements of virtual reality technology in dance teaching. China Educational Technology. 6, 85–88. Available from: https://qikan.cqvip.com/Qikan/Article/Detail?id=49886377 (cited15 May 2025).

[2] Sims, C.N., 2020. Dance Movement Visualization

and Education in Virtual Reality [Ph.D. Thesis]. College Station, TX, USA: Texas A&M University.
[3] Chan, J.C.P., Leung, H., Tang, J.K.T., et al., 2011. A Virtual Reality Dance Training System Using Motion Capture Technology. IEEE Transactions on Learning Technologies. 4(2), 187–195. DOI: https://doi.org/10.1109/TLT.2010.27
[4] Liu, M., 2022. Application of Cloud Service-Oriented Heterogeneous Execution Scheduling and VR Technology in Dance Video Teaching. Mathematical Problems in Engineering. (1), 5084230. DOI: https://doi.org/10.1155/2022/5084230
[5] Dania, A., Hatziharistos, D., Koutsouba, M., et al., 2011. The use of technology in movement and dance education: Recent practices and future perspectives. Procedia - Social and Behavioral Sciences. 15, 3355–3361. DOI: https://doi.org/10.1016/j.sbspro.2011.04.299
[6] Hargreaves, D.H., 1997. In Defence of Research for Evidence-based Teaching: A rejoinder to Martyn Hammersley. British Educational Research Journal. 23(4), 405–419. DOI: https://doi.org/10.1080/0141192970230402
[7] Yang, K.H., 2018. Evidence-based social science: The origin, development and prospects. Library & Information. 3, 1–10. Available from: https://qikan.cqvip.com/Qikan/Article/Detail?id=7000833009&from=Qikan_Search_Index (cited15 May 2025).
[8] Gurevitch, J., Koricheva, J., Nakagawa, S., et al., 2018. Meta-analysis and the science of research synthesis. Nature. 555(7695), 175–182. DOI: https://doi.org/10.1038/nature25753
[9] Page, M.J., McKenzie, J.E., Bossuyt, P.M., et al., 2021. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Systematic Reviews. 10(1), 89. DOI: https://doi.org/10.1186/s13643-021-01626-4
[10] Chen, X., Hu, Z., Wang, C., 2024. Empowering education development through AIGC: A systematic literature review. Education and Information Technologies. 29(13), 17485–17537. DOI: https://doi.org/10.1007/s10639-024-12549-7
[11] Radianti, J., Majchrzak, T.A., Fromm, J., et al., 2020. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education. 147, 103778. DOI: https://doi.org/10.1016/j.compedu.2019.103778
[12] Lanszki, A., Tongori,Á., Papp-Danka, A., 2023. Dance-Related Research In Tertiary Education: A Systematic Literature Review. Tánc És Nevelés. 4(2), 29–53. DOI: https://doi.org/10.46819/TN.4.2.3-27
[13] Milling, S., Green, S.K., 2014. Progress and Process in a Choreography Class: Addressing Formative and Summative Assessment Issues. Journal of Dance Education. 14(4), 146–151. DOI: https://doi.org/10.1080/15290824.2014.873127
[14] Liu, M., 2011. Systematic Review and Meta-Analysis: Design and Implementation Methods. People's Medical Publishing House. Available from: https://books.google.com.hk/books/about/%E7%B3%BB%E7%BB%9F%E8%AF%84%E4%BB%B7_Meta_%E5%88%86%E6%9E%90%E8%AE%BE%E8%AE%A1%E4%B8%8E%E5%AE%9E%E6%96%BD.html?id=fSbbnQEACAAJ&redir_esc=y (cited15 May 2025).
[15] Jacob, C., 1992. A power primer. Psychological Bulletin. 112(1), 155–159.
[16] Guang, F., Xueliang, Z., 2025. Research on the impact mechanisms of immersive virtual reality technology in enhancing the effectiveness of higher folk dance education: Base on student perspective. Education and Information Technologies. DOI: https://doi.org/10.1007/s10639-025-13413-y
[17] Zhang, N., 2022. 3D Digital Model of Folk Dance Based on Few-Shot Learning and Gesture Recognition. Computational Intelligence and Neuroscience. (1), 3682261. DOI: https://doi.org/10.1155/2022/3682261
[18] Chua, P.T., Crivella, R., Daly, B., et al., 2003. Training for physical tasks in virtual environments: Tai Chi. Proceedings of the IEEE Virtual Reality, 2003. Proceedings; Los Angeles, CA, USA; 22–26 March 2003; pp. 87–94. DOI: https://doi.org/10.1109/VR.2003.1191125
[19] Li, Y., Patoglu, V., O'Malley, M.K., 2009. Negative efficacy of fixed gain error reducing shared control for training in virtual environments. ACM Transactions on Applied Perception. 6(1), 3:1–3:21. DOI: https://doi.org/10.1145/1462055.1462058
[20] Kozak, J.J., Hancock, P.A., Arthur, E.J., et al., 1993. Transfer of training from virtual reality. Ergonomics. 36(7), 777–784. DOI: https://doi.org/10.1080/00140139308967941
[21] Lintern, G., 1991. An Informational Perspective on skill Transfer in Human-Machine Systems. Human Factors. 33(3), 251–266. DOI: https://doi.org/10.1177/001872089103300302
[22] Gamberini, L., 2000. Virtual Reality as a New Research Tool for the Study of Human Memory. CyberPsychology & Behavior. 3(3), 337–342. DOI: https://doi.org/10.1089/10949310050078779
[23] Chen, Y., Zhang, Y., 2024. A study on the application of digital technology in improving the quality and effectiveness of dance teaching. Applied Mathematics and Nonlinear Sciences. 9(1), 1–17. DOI: https://doi.org/10.2478/amns.2023.2.00707
[24] Jiang, T.H., 2019. Research on the control of emotion and breath in dance performances. Journal of Beijing Dance Academy. 6, 109–112. Available from: https://qikan.cqvip.com/Qikan/Article/Detail?id=7101888550&from=Qikan_Search_Index

(cited15 May 2025).
[25] Sawada, M., Suda, K., Ishii, M., 2003. Expression of Emotions in Dance: Relation between Arm Movement Characteristics and Emotion. Perceptual and Motor Skills. 97(3), 697–708. DOI: https://doi.org/10.2466/pms.2003.97.3.697
[26] Wang, Z., 2024. Artificial intelligence in dance education: Using immersive technologies for teaching dance skills. Technology in Society. 77, 102579. DOI: https://doi.org/10.1016/j.techsoc.2024.102579
[27] Kirsh, D., 2013. Embodied cognition and the magical future of interaction design. ACM Transactions on Computer-Human Interaction. 20(1), 3:1–3:30. DOI: https://doi.org/10.1145/2442106.2442109
[28] Witt, J.K., 2011. Action's Effect on Perception. Current Directions in Psychological Science. 20(3), 201–206. DOI: https://doi.org/10.1177/0963721411408770
[29] Dreyfus, H.L., 1990. Being-in-the-World: A Commentary on Heidegger's Being in Time, Division I. MIT Press: Cambridge, MA, USA.
[30] Kaplan, D.M., 2009. Readings in the Philosophy of Technology. Rowman & Littlefield Publishers: Lanham, MD, USA.
[31] Sobchack, V., 2004. Carnal Thoughts: Embodiment and Moving Image Culture. University of California Press: Oakland, CA, USA.
[32] Jiang, W., Windl, M., Tag, B., et al., 2024. An Immersive and Interactive VR Dataset to Elicit Emotions. IEEE Transactions on Visualization and Computer Graphics. DOI: https://doi.org/10.1109/TVCG.2024.3456202
[33] Zhao, Y., 2022. Teaching traditional Yao dance in the digital environment: Forms of managing subcultural forms of cultural capital in the practice of local creative industries. Technology in Society. 69, 101943. DOI: https://doi.org/10.1016/j.techsoc.2022.101943