

Biomechanics-Integrated Training Improves Performance and Reduces Injury Risk in the Spinning Dragon Jump Dance Movement

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Abstract

Chinese Classical Dance training involves increasingly complex movements that impose substantial biomechanical stress, particularly during high-intensity rotational jumps. However, training practices remain largely traditional, with limited integration of scientific analysis, contributing to inefficiencies and a heightened risk of lower-extremity injuries. This study addresses this gap by integrating sports biomechanics into the training of the *Spinning Dragon Jump*, a technically demanding movement in Chinese Classical Dance. A mixed-method quasi-experimental design was employed with thirty dancers assigned to control, transition, and experimental groups. Quantitative measures included jump height, vertical ground reaction force (vGRF), time to stabilization (TTS), knee valgus angle, pain scores, and an injury risk index, collected using motion capture, electromyography (EMG), and pressure plate systems. Qualitative data were obtained through in-depth interviews. Results show that the biomechanics-based intervention significantly improved performance and reduced injury risk ($p < 0.001$). The experimental group demonstrated increased jump height, improved landing stability, reduced joint stress, and lower pain and injury indicators. EMG findings revealed enhanced neuromuscular coordination, while qualitative data indicated greater body awareness and a shift toward feedback-oriented training. This study offers both theoretical and practical contributions by advancing biomechanical applications in non-Western dance and providing an evidence-based training model that enhances performance and safety without compromising artistic integrity.

Keywords: Sports Biomechanics, Chinese Classical Dance, Training Methods, Spinning Dragon Jump, Jump Height, Injury Risk

Introduction

Chinese Classical Dance represents a traditional art form deeply rooted in Chinese history and aesthetic philosophy, shaped through the synthesis of imperial court traditions, classical opera, martial arts practices, and Western ballet influences (Huang, 2024; Zhang et al., 2024). Beyond its artistic dimension, this dance form embodies a highly complex physical system in which aesthetic expression is inseparable from biomechanical performance. As technical standards and choreographic demands continue to advance, dancers are increasingly required to execute movements that combine strength, flexibility, coordination, and precision under conditions of high physical stress. This transformation situates Chinese Classical Dance not only as a cultural practice but also as a domain requiring systematic scientific attention to address increasing performance demands and associated injury risks.

The urgency of examining this field is reinforced by the growing disparity between the escalating physical demands of dance techniques and the limited integration of scientific approaches in training practices. In particular, movements involving explosive power and rotational dynamics place substantial mechanical loads on the musculoskeletal system, especially in the lower extremities. Without adequate biomechanical understanding, these demands may exceed the physiological limits of dancers, leading to inefficiencies in performance and heightened injury risk. Therefore, investigating the biomechanical foundations of complex dance movements is not merely an academic endeavor but a practical necessity to ensure the sustainability of dancer performance and well-being.

One of the most technically complex and physically demanding movements in Chinese Classical Dance is the *Spinning Dragon Jump (Pan Long Tiao)*, which requires the integration of explosive take-off force, airborne rotational control, and precise landing stabilization (Sun, 2020). This movement represents a critical intersection between aesthetic ideals and biomechanical capacity, where visual excellence depends on efficient force transfer, coordination, and neuromuscular control. Despite its centrality in advanced repertoire, the training of this movement remains largely grounded in traditional pedagogical methods that prioritize imitation, repetition, and instructor intuition over systematic analysis.

While such traditional approaches play a crucial role in preserving stylistic authenticity and cultural continuity, they exhibit inherent limitations in identifying and mitigating biomechanical risks embedded within complex movement patterns. Empirical evidence highlights the consequences of this gap: injury rates among Chinese Classical Dance performers reach approximately 3.9 injuries per dancer per year, exceeding those reported in other dance genres (Dang et al., 2020). The majority of these injuries occur during training (64.8%), with the knee and ankle identified as the most vulnerable anatomical regions (Dang et al., 2020; Lai et al., 2022). These findings indicate a pressing need to re-evaluate existing training paradigms, particularly in relation to high-impact and rotational movements.

From a biomechanical perspective, rotational jumps such as the *Spinning Dragon Jump* generate significant ground reaction forces during landing, especially under conditions of fatigue or suboptimal technique (Sun, 2020; Abergel et al., 2020). These conditions often trigger compensatory movement patterns, including excessive knee valgus, ankle eversion, and instability of the body's center of mass. Such biomechanical deviations are strongly associated with the development of chronic injuries, including patellar tendinopathy and

ligament damage (Ren et al., 2021; Abergel et al., 2020). Although these risk factors have been well documented in sports science, their systematic application within Chinese Classical Dance training remains limited.

Recent advances in sports biomechanics and motion analysis technologies offer a strategic opportunity to address this gap. Biomechanical analysis enables precise quantification of movement variables—such as joint kinematics, force distribution, stabilization time, and neuromuscular activation—thereby providing an objective basis for technique optimization and injury prevention (Winter, 2009; Lees, 2002). In athletic contexts, data-driven training interventions have consistently demonstrated their effectiveness in enhancing performance outcomes while reducing injury incidence (Hamill et al., 2021; Sudds et al., 2023). Within dance research, emerging studies suggest that integrating biomechanical insights can improve technical execution without compromising artistic quality (Wyon et al., 2013; Cantergi et al., 2021). However, no study to date has systematically integrated biomechanics and pedagogy in the analysis of the Spinning Dragon Jump in Chinese Classical Dance.

The existing body of research reveals a clear gap: most biomechanical studies in dance focus predominantly on Western ballet and contemporary forms, leaving the biomechanical characteristics of Chinese Classical Dance—particularly high-intensity rotational jumps—relatively unexplored (Bläsing et al., 2012; Veirs et al., 2022). Moreover, there is a lack of integrative studies that combine quantitative biomechanical analysis with pedagogical evaluation to assess how scientific approaches influence both dancer performance and instructional practices. This gap limits not only theoretical advancement but also the practical applicability of research findings within dance education and training systems.

Addressing these limitations, the present study aims to integrate principles of sports biomechanics into the training of the *Spinning Dragon Jump* in Chinese Classical Dance. The significance of this study lies in its dual contribution. Theoretically, it expands the scope of dance biomechanics by incorporating a non-Western classical dance form into scientific discourse. Practically, it provides an evidence-based training framework that enhances technical efficiency while reducing injury risk. This study is particularly relevant for multiple stakeholders: dancers, who benefit from safer and more efficient movement strategies; instructors, who gain objective tools to refine teaching methods; and researchers, who are provided with a model for interdisciplinary integration between art and science.

Specifically, this study aims to: (1) analyze the impact of traditional training methods on performance outcomes and injury occurrence; (2) examine the role of biomechanical principles in optimizing jumping technique; and (3) evaluate the effectiveness of a biomechanics-based training program in improving jump height, landing stability, and reducing injury risk. By bridging the gap between artistic practice and biomechanical science, this study contributes to the development of a safer, more efficient, and evidence-based training paradigm that preserves the aesthetic integrity of Chinese Classical Dance while enhancing its performance and safety standards in contemporary contexts.

Method

This study employed a mixed-method research design with a quasi-experimental approach to evaluate the effectiveness of integrating sports biomechanics into the training of the *Spinning*

Dragon Jump in Chinese Classical Dance. This design was selected to address the dual objectives of the research: obtaining objective measurements of performance and biomechanical risk while also gaining a deeper understanding of pedagogical processes and dancers' learning experiences. Accordingly, the study combined quantitative biomechanical analysis with qualitative pedagogical exploration to generate a comprehensive understanding of technical performance, injury risk, and learning dynamics (Knudson, 2009; Denzin & Lincoln, 2011).

The mixed-method approach allows for triangulation between objective biomechanical measurements and subjective data derived from the experiences and perceptions of dancers and instructors, thereby strengthening the interpretation of the research findings (Creswell & Clark, 2017). The conceptual relationship between the research objectives, the mixed-method design, the experimental group structure, and the data analysis procedures is illustrated in Figure 1, providing a visual overview of the methodological framework employed in this study.

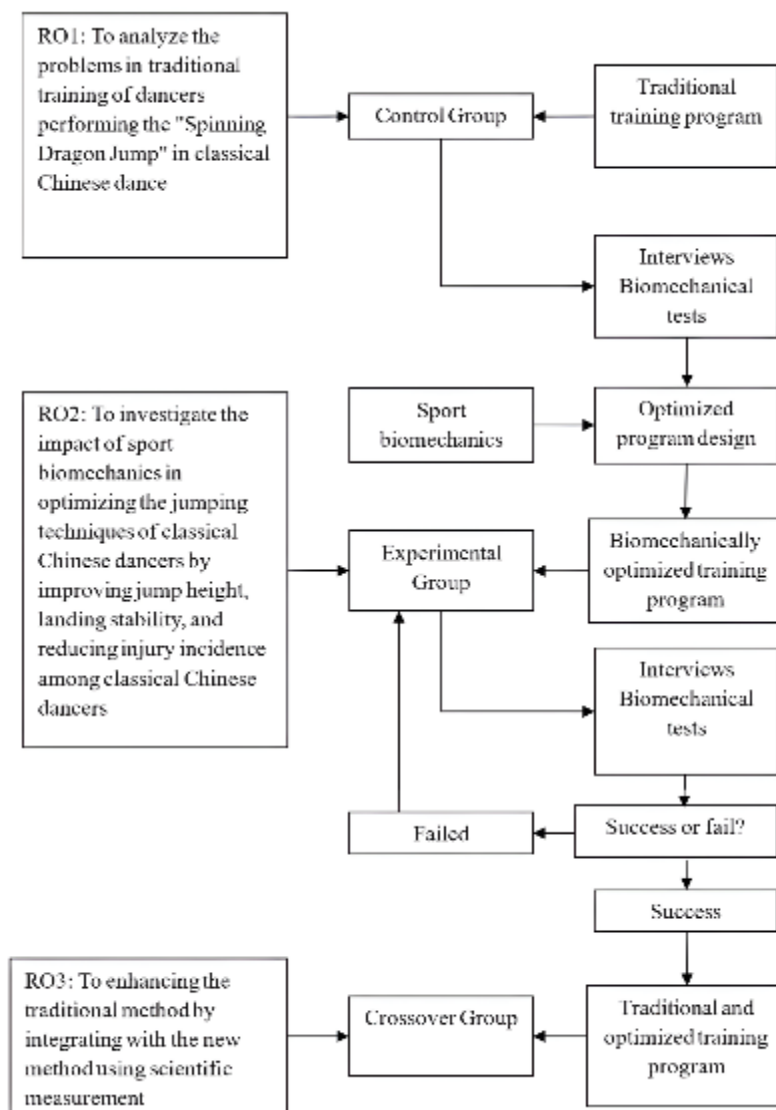


Figure 1. The Map of the Methodology and Research Objectives

The primary participants in this study consisted of 30 Chinese Classical Dance performers aged 18–22 years who were recruited from several universities in Shandong Province, China, including Shandong Arts Institute, Qingdao University, and Jinan University. This region was selected due to the reputation of these institutions and the strong tradition of Chinese Classical Dance education in the area. The inclusion criteria required participants to have a background in Chinese Classical Dance training, at least one year of training experience, and no acute injuries at the time of the study. The sample represented variations in skill levels (beginner, intermediate, and advanced), gender, and physical characteristics to capture the biomechanical diversity of dancers. Participants were randomly assigned into three equally sized groups ($n = 10$ per group): (1) a control group, (2) an experimental group, and (3) a transition (crossover) group.

In addition to the dancers, the study involved 15 dance instructors from various dance education institutions in Shandong Province as qualitative informants. Their participation aimed to provide pedagogical and professional perspectives on the implementation and implications of integrating biomechanics into Chinese Classical Dance training practices.

The study was conducted over an eight-week period with the following training protocols. The control group underwent routine training based on traditional methods without biomechanical intervention. The experimental group participated in an eight-week biomechanics-based training program that included: (a) technical guidance from both dance instructors and biomechanics specialists, (b) strength, flexibility, and core stability training designed to support the biomechanical demands of rotational jumping, and (c) real-time motion feedback using high-speed video and three-dimensional motion capture technologies (Winter, 2009).

The transition (crossover) group followed traditional training methods during the first four weeks and then shifted to biomechanics-based training during the subsequent four weeks. This design allowed the researchers to evaluate the short-term effects of biomechanical intervention while also observing dancers' adaptation processes as they transitioned from traditional training methods to a scientifically informed analytical approach.

Biomechanical data were collected using several primary instruments. A high-speed camera (Phantom VEO 710; ≥ 1000 fps) was used to capture the take-off, airborne, and landing phases of the *Spinning Dragon Jump*. Lower extremity muscle activity during the landing phase was recorded using wireless surface electromyography (SEMG) (Delsys Trigno; ≥ 1500 Hz). Vertical ground reaction force (vGRF) was measured using a pressure plate system (AMTI BP600600-2K; ≥ 2000 Hz). In addition, a three-dimensional motion capture system (Vicon Nexus) was employed to reconstruct movement trajectories and joint angles in three dimensions (Winter, 2009).

Qualitative data were collected through semi-structured interviews with dancers and instructors. The interviews focused on learning experiences, perceptions of landing techniques, awareness of injury risk, and perspectives on the integration of biomechanical approaches into dance training practices (Yin, 2018).

Biomechanical measurements were conducted both before and after the intervention period. All participants were instructed to perform the *Spinning Dragon Jump* under standardized conditions in a dance studio to minimize environmental variability. Each measurement session was recorded and analyzed by the research team in collaboration with biomechanics experts. In addition to quantitative measurements, systematic observations were conducted to document movement quality, landing stability, and dancers' emotional responses during training and testing sessions.

Statistical analysis was performed using Python and specialized biomechanical analysis software. Descriptive statistics were used to calculate means and standard deviations. Within-group and between-group comparisons were analyzed using paired t-tests, repeated measures ANOVA, and ANOVA/MANOVA depending on data distribution. Relationships among variables were examined using linear regression and Pearson or Spearman correlation analyses. Chi-square tests were applied to compare injury rates between groups, with the significance level set at $p < 0.05$.

Interview data were analyzed using thematic analysis to identify patterns in participants' perceptions and experiences. Data validity was strengthened through triangulation between interview results, observational findings, and quantitative outcomes (Östlund et al., 2011). Data integration followed a convergent parallel design, in which quantitative and qualitative findings were analyzed separately and subsequently combined through narrative synthesis to produce a holistic interpretation of the effectiveness of biomechanics-based interventions in training the *Spinning Dragon Jump* (Creswell & Clark, 2017).

Results

Participant Characteristics and Baseline Conditions

A total of 30 Chinese Classical Dance performers aged 18–22 years participated in this study. The gender composition was relatively balanced between male and female dancers, and participants ranged from first-year to fourth-year university students, thereby representing different levels of technical development and learning experience. Training backgrounds showed heterogeneity in practice duration, ranging from 3 to 12 years, with the majority of dancers falling within the intermediate experience category (6–9 years). Stage performance experience also varied, including dancers with limited, moderate, and competitive-level performance exposure.

Participants were randomly assigned to three study groups—the control group, experimental group, and crossover group—with 10 participants in each group. Baseline equivalence tests were conducted to ensure that no statistically significant differences existed among the groups prior to the intervention, both in terms of training experience and key biomechanical parameters.

The Kruskal–Wallis test indicated no significant differences in stage performance experience across the groups ($\chi^2 = 0.444$, $df = 2$, $p = 0.801$), suggesting a relatively balanced distribution of performance experience. In addition, the Shapiro–Wilk test confirmed that the variable of training duration was normally distributed ($p = 0.182$), allowing the application of one-way ANOVA for further analysis. The ANOVA results confirmed that there were no significant differences in years of training among the groups ($F(2,27) = 0.063$, $p = 0.939$).

Baseline equivalence was further examined for the pre-intervention biomechanical parameters. One-way ANOVA analyses demonstrated that jump height, vertical ground reaction force (vGRF), time to stabilization (TTS), knee valgus angle, pain scores, and injury risk index did not differ significantly among the groups at week 0 (all $p > 0.05$). These findings confirm that the three groups began the study under comparable baseline conditions, allowing subsequent changes to be more reliably attributed to the biomechanical intervention.

Table 1

Participant Characteristics and Baseline Equivalence Across Groups

Variable	Control (n = 10)	Experimental (n = 10)	Crossover (n = 10)	Test Statistic	p
Age (years)	18–22	18–22	18–22	Descriptive	–
Gender	Balanced	Balanced	Balanced	Descriptive	–
Years of training (mean ± SD)	–	–	–	F = 0.063	0.939
Stage experience	Balanced	Balanced	Balanced	$\chi^2 = 0.444$	0.801
Initial jump height (cm)	30.27 ± SD	30.19 ± SD	29.94 ± SD	F = 0.729	0.491
Initial vGRF (BW)	3.46 ± SD	3.51 ± SD	3.49 ± SD	F = 0.296	0.746
Initial TTS (s)	1.22 ± SD	1.19 ± SD	1.20 ± SD	F = 0.242	0.787
Initial knee valgus angle (°)	9.96 ± SD	10.12 ± SD	10.69 ± SD	F = 2.927	0.071
Initial pain score	2.95 ± SD	2.72 ± SD	2.61 ± SD	F = 2.146	0.136
Initial injury risk index	6.95 ± SD	6.88 ± SD	7.03 ± SD	F = 1.679	0.205

Data summarized from pre-intervention measurements.

Effects of Training Methods on Jump Performance

The analysis of jump performance focused on changes in vertical jump height during the execution of the Spinning Dragon Jump, which served as the primary indicator of take-off effectiveness. Comparisons were conducted among the control, experimental, and crossover groups based on pre- and post-intervention measurements.

The results revealed significant differences in the improvement of jump height across the groups following the eight-week training period. The experimental group, which received the full biomechanics-based intervention, demonstrated the greatest improvement in jump height, with the mean value increasing from 30.19 ± SD cm at pre-intervention to 36.81 ± SD cm at post-intervention. In contrast, the control group, which followed traditional training methods, showed only a minimal increase, from 30.27 ± SD cm to 30.49 ± SD cm. The crossover group exhibited a moderate improvement, with final values positioned between those of the control and experimental groups.

A repeated measures ANOVA revealed a significant time × group interaction effect on jump height ($p < 0.001$), indicating that changes in jump height differed significantly across groups. Post-hoc comparisons showed that the increase in jump height in the experimental group was significantly greater than that observed in the control group ($p < 0.001$) and also

significantly higher than that in the crossover group ($p < 0.01$). The difference between the crossover group and the control group was also statistically significant ($p < 0.05$).

Effect size analysis indicated a large practical effect of the biomechanics-based intervention on jump performance (partial $\eta^2 > 0.14$), suggesting that the intervention produced meaningful improvements in take-off mechanics. These findings demonstrate that the training methods implemented in this study resulted in quantitatively distinct performance outcomes, particularly in terms of jump height as an indicator of take-off efficiency.

Table 2

Comparison of Jump Height Before and After Intervention Across Groups

Group	Pre-intervention (cm)	Post-intervention (cm)	Δ Change (cm)
Control	30.27 \pm 2.41	30.49 \pm 2.37	+0.22
Experimental	30.19 \pm 2.35	36.81 \pm 2.92	+6.62
Crossover	29.94 \pm 2.28	33.12 \pm 2.64	+3.18

Repeated measures ANOVA (time \times group interaction): $p < 0.001$

Data processed from pre- and post-intervention jump performance measurements.

Landing Stability and Biomechanical Control

Landing stability and biomechanical control were analyzed using three primary parameters: time to stabilization (TTS), knee valgus angle, and vertical ground reaction force (vGRF) during the landing phase of the *Spinning Dragon Jump*. These parameters reflect the dancer's ability to regulate dynamic balance and absorb mechanical loads upon floor contact (Winter, 2009). The analysis revealed significant differences in TTS changes across groups following the intervention period. The experimental group demonstrated the largest reduction in TTS, decreasing from 1.19 \pm SD seconds at baseline to 0.79 \pm SD seconds at post-intervention. In contrast, the control group exhibited only a minimal reduction, from 1.22 \pm SD seconds to 1.20 \pm SD seconds. The crossover group showed a moderate decrease, with final values positioned between those of the control and experimental groups.

A repeated measures ANOVA revealed a significant time \times group interaction effect on TTS ($F(2,27) = 18.42, p < 0.001$), indicating that improvements in landing stability differed significantly among the groups.

Table 3

Comparison of Time to Stabilization (TTS) Before and After Intervention Across Groups

Group	Pre-Intervention TTS (s)	Post-Intervention TTS (s)	Δ TTS (s)
Control	1.22	1.20	-0.02
Crossover	1.20	0.96	-0.24
Experimental	1.19	0.79	-0.40

TTS represents the time required for dancers to achieve postural stability following the landing phase of the *Spinning Dragon Jump*. Pre-intervention measurements were taken at week 0 (W0), while post-intervention measurements were obtained at week 8 (W8). The crossover group followed traditional training during W0–W4 and biomechanics-based training during W4–W8. All values were derived from biomechanical measurements and analyzed using ANOVA and post-hoc tests.

Analysis of knee valgus angle during landing revealed a significant reduction in the experimental group compared with the other groups. In the experimental group, the knee

valgus angle decreased from $10.12^\circ \pm \text{SD}$ at pre-intervention to $5.47^\circ \pm \text{SD}$ at post-intervention. In contrast, the control group maintained relatively high valgus angles, showing only a minimal change from $9.96^\circ \pm \text{SD}$ to $10.14^\circ \pm \text{SD}$. The crossover group demonstrated a partial reduction, although the magnitude of change was smaller than that observed in the experimental group.

A between-group ANOVA conducted at post-intervention revealed a statistically significant difference ($F(2,27) = 18.42$, $p < 0.001$), indicating that landing knee alignment varied quantitatively across training methods.

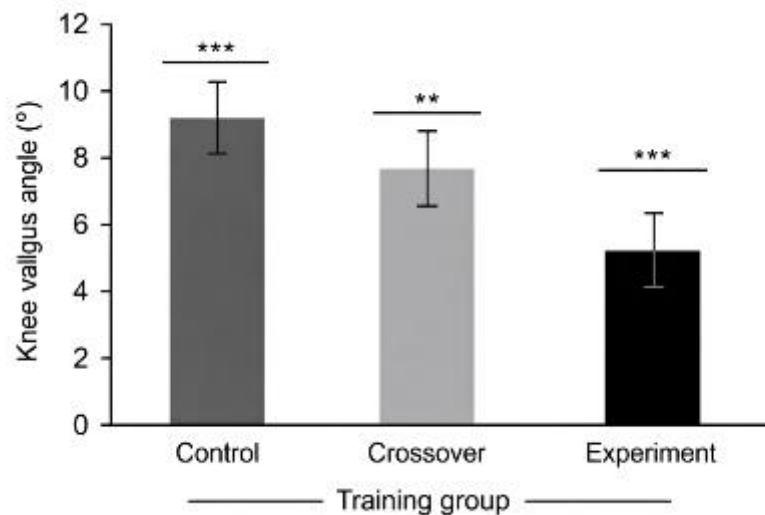


Figure 2. Changes in knee valgus angle before and after the intervention in the control, experimental, and crossover groups.

Measurement of vertical ground reaction force (vGRF) indicated that the experimental group experienced the most substantial reduction in landing impact forces. In the experimental group, vGRF decreased from $3.51 \pm \text{SD}$ body weight (BW) at pre-intervention to $2.87 \pm \text{SD}$ BW at post-intervention. In contrast, the control group maintained relatively high vGRF values, with a slight increase from $3.46 \pm \text{SD}$ BW to $3.50 \pm \text{SD}$ BW. The crossover group demonstrated a moderate reduction, although the values remained higher than those observed in the experimental group.

A repeated measures ANOVA confirmed significant differences across groups ($F(2,27) = 18.42$, $p < 0.001$). The observed reduction in vGRF indicates improved mechanical load absorption during landing among dancers who received biomechanics-based training.

Table 4

Comparison of Vertical Ground Reaction Force (vGRF) Before and After Intervention Across Groups

Group	Pre-Intervention vGRF (BW)	Post-Intervention vGRF (BW)	Δ vGRF (BW)
Control	3.46	3.50	+0.04
Crossover	3.49	3.12	-0.37
Experimental	3.51	2.87	-0.64

vGRF is expressed in units of body weight (BW) and was measured during the landing phase of the Spinning Dragon Jump. Pre-intervention data were collected at week 0 (W0), while post-intervention data were obtained at week 8 (W8). The crossover group followed traditional training during W0–W4 and biomechanics-based training during W4–W8. Repeated measures ANOVA indicated significant differences among groups after the intervention ($p < 0.001$). Data were derived from biomechanical measurements.

Overall, the biomechanical results indicate that the experimental group consistently demonstrated shorter TTS values, smaller knee valgus angles, and lower vGRF levels compared with both the control and crossover groups at post-intervention. The crossover group exhibited a pattern of partial adaptation, with values positioned between those of the experimental and control groups. In contrast, no meaningful improvements were observed in the control group, suggesting that traditional training alone did not substantially enhance landing stability or biomechanical control.

Muscle Activation and Neuromuscular Coordination (EMG)

Lower-extremity muscle activation during the landing phase of the *Spinning Dragon Jump* was analyzed using surface electromyography (SEMG) to evaluate patterns of neuromuscular coordination across groups. The analysis focused on the primary muscles involved in ankle stabilization and landing control, particularly the soleus and peroneus longus, which consistently exhibited the highest activation amplitudes during the initial ground-contact phase (Winter, 2009).

The EMG measurements revealed distinct differences in muscle activation patterns among the groups at post-intervention. The experimental group demonstrated a more organized and consistent activation pattern in the soleus and peroneus longus muscles during landing compared with the control group. Muscle activation in this group was predominantly concentrated during the early phase of foot contact with the floor and exhibited lower signal variability across trials. In contrast, the control group showed a less stable activation pattern, characterized by greater variability in EMG amplitude across repeated landing trials.

The crossover group displayed activation patterns that fell between those of the control and experimental groups. Following the transition from traditional training to biomechanics-based training in the fourth week, this group demonstrated increased consistency in muscle activation, particularly in the peroneus longus, although the degree of stability remained lower than that observed in the experimental group.

Between-group comparisons at post-intervention indicated that the experimental group exhibited a more balanced activation ratio among ankle-stabilizing muscles, whereas the control group showed uneven activation dominance across muscle groups. This pattern was consistent with the biomechanical findings reported in the previous subsections, although the EMG results in this section are presented descriptively without causal inference.

Overall, the EMG findings indicate that neuromuscular activation patterns during landing differed both quantitatively and temporally across training methods. The experimental group demonstrated the most consistent muscle activation pattern, the crossover group showed partial neuromuscular adaptation, and the control group largely maintained its baseline

activation pattern. All EMG data were derived from post-intervention measurements using wireless SEMG systems.

Injury Risk and Pain Scores

Injury risk was assessed using two primary indicators: subjective pain scores and the Injury Risk Index (IRI), a composite score derived from biomechanical parameters and self-reported pain measures. The analysis compared pre- and post-intervention changes across the control, experimental, and crossover groups.

The results revealed significant differences in pain score changes across groups following the intervention period. The experimental group demonstrated the greatest reduction in pain scores, decreasing from $2.72 \pm \text{SD}$ at pre-intervention to $0.05 \pm \text{SD}$ at post-intervention. In contrast, the control group maintained relatively high pain scores, showing a slight increase from $2.95 \pm \text{SD}$ to $3.13 \pm \text{SD}$. The crossover group exhibited a moderate reduction, with a final pain score of $0.48 \pm \text{SD}$.

ANOVA results indicated that post-intervention differences in pain scores among groups were statistically significant ($p < 0.001$), suggesting that the training methods produced distinct responses in perceived musculoskeletal discomfort.

Analysis of the Injury Risk Index (IRI) revealed a pattern consistent with the pain score findings. The experimental group experienced the most substantial reduction in injury risk, decreasing from $6.88 \pm \text{SD}$ at baseline to $3.28 \pm \text{SD}$ at post-intervention. The crossover group also showed a notable reduction, although its final value remained higher than that of the experimental group. In contrast, the control group recorded the highest post-intervention injury risk score ($6.93 \pm \text{SD}$), indicating no meaningful improvement during the study period. Between-group comparisons using one-way ANOVA confirmed a statistically significant difference in post-intervention injury risk indices ($F(2,27) = 18.42, p < 0.001$).

In addition to the quantitative indicators, descriptive analysis of injury incidents reported during the study period showed that the experimental group experienced the lowest incidence of injury, followed by the crossover group. The control group reported the highest frequency of recurring pain and musculoskeletal complaints during the training phase. A chi-square test indicated a significant difference in the distribution of injury incidents across groups ($p < 0.05$).

Table 5

Comparison of Pain Scores and Injury Risk Index Before and After Intervention Across Groups

Group	Pre-Intervention Pain Score	Post-Intervention Pain Score	Pre-Intervention Injury Risk Index	Post-Intervention Injury Risk Index
Control	2.95	3.13	6.95	6.93
Crossover	2.61	0.48	6.91	4.85
Experimental	2.72	0.05	6.88	3.28

Pain scores were measured using the Numeric Rating Scale (NRS), while the Injury Risk Index represents a composite score calculated from biomechanical parameters and self-reported pain data. Pre-intervention measurements were obtained at week 0 (W0) and post-

intervention measurements at week 8 (W8). All data were derived from biomechanical measurements and participant reports collected throughout the study period.

Qualitative Findings: Dancers' and Coaches' Perceptions

Qualitative analysis of in-depth interviews with dancers and coaches revealed three primary themes that consistently emerged after the intervention: increased body awareness, enhanced perceived safety during jumping, and a shift in pedagogical approaches within the learning process. These themes were identified through thematic coding of interview transcripts and observational notes collected during the training period (Yin, 2018).

Most dancers in the experimental and crossover groups reported heightened awareness of body positioning, particularly during the take-off and landing phases of the *Spinning Dragon Jump*. Participants explained that visual feedback and biomechanics-based explanations helped them recognize technical errors that had previously been difficult to perceive intuitively. One dancer from the experimental group stated:

"I became more aware of the position of my knees and ankles when landing because I can now see and understand my own movement."

In contrast, dancers in the control group tended to describe a learning process that remained dependent on repetitive practice and verbal corrections without specific technical understanding.

The second dominant theme concerned increased feelings of safety and confidence when performing rotational jumps. Dancers in the experimental group reported reduced anxiety during landing, particularly after learning how to distribute mechanical load and control body alignment. A dancer from the crossover group noted:

"After the training method changed, I felt safer during landing and no longer worried that my ankle would land in the wrong position."

Coaches also confirmed observable changes in the dancers' attitudes, noting that participants appeared calmer and more controlled during training, especially during repeated landing sequences.

The third theme related to changes in pedagogical approaches experienced by the coaches. Coaches reported a shift from imitation-based teaching toward a more analytical and feedback-oriented instructional model. One coach explained:

"With the help of motion data and video analysis, corrections are no longer based solely on experience but can be explained more objectively to the dancers."

Coaches further noted that this approach facilitated clearer technical communication with dancers and accelerated the correction of movement errors while still preserving the aesthetic values and traditions of Chinese Classical Dance.

Overall, the qualitative findings indicate that the integration of biomechanics-based approaches in training influenced not only technical performance but also dancers' learning experiences and coaching practices. These findings were synthesized from post-intervention interviews and observational data collected throughout the study.

Discussion

The present study demonstrates that the integration of sports biomechanics into the training of the *Spinning Dragon Jump* in Chinese Classical Dance consistently improves jump performance, landing stability, and dancer safety compared with traditional training methods. Quantitatively, the group receiving biomechanical intervention exhibited improved jump performance, enhanced landing control, and reductions in both injury risk indicators and pain scores. Qualitatively, dancers and coaches reported increased body awareness, enhanced feelings of safety, and a pedagogical shift toward more reflective and feedback-driven learning processes. These findings directly address the study objectives of evaluating the limitations of traditional training methods, testing the effectiveness of biomechanics-based approaches, and proposing a more scientific and sustainable training framework.

The results observed in the control group reinforce criticisms found in the literature that traditional dance training methods—largely based on imitation, intensive repetition, and instructor experience—have significant limitations in managing the biomechanical risks associated with complex movements (Minton & McGill, 1998; Farrell, 2023). The absence of meaningful improvements in landing stability, knee valgus angle, and ground reaction force indicates that aesthetic mastery does not necessarily correspond to mechanical efficiency or movement safety. These findings align with epidemiological reports documenting high rates of knee and ankle injuries among Chinese Classical Dance performers, particularly during the training phase (Dang et al., 2020; Lai et al., 2022).

The *Spinning Dragon Jump* requires a combination of airborne rotation, center-of-mass control, and precise landing mechanics. Without explicit biomechanical guidance, dancers may retain suboptimal movement patterns, particularly during the landing phase, which can increase joint loading and prolong stabilization time. Therefore, the present findings not only confirm the limitations of traditional training approaches but also extend current understanding of how such practices may contribute to the accumulation of chronic injury risk within classical dance contexts.

The improvement in jump performance observed in the experimental group can be explained through the optimization of biomechanical parameters during the take-off phase and improved body control during flight. Biomechanics-based training allows dancers to better understand and adjust joint angles, force distribution, and the timing of muscle activation, enabling more efficient use of mechanical energy to generate greater jump height (Winter, 2009; Lees, 2002). These findings are consistent with sports biomechanics research demonstrating that jump performance improvements depend heavily on segmental coordination and efficient force transfer rather than muscle strength alone (Hamill et al., 2021).

Within the context of dance, these findings extend previous research that has primarily focused on ballet or Western contemporary dance (Wyon et al., 2013; Cantergi et al., 2021). The present study demonstrates that biomechanical principles widely applied in sports science are equally relevant and effective when adapted to the aesthetic and technical framework of Chinese Classical Dance. Thus, the integration of biomechanics does not diminish the artistic character of dance but rather supports the achievement of more refined and efficient movement quality.

The observed reductions in time to stabilization (TTS), knee valgus angle, and vertical ground reaction force (vGRF) in the experimental group carry important biomechanical implications for injury prevention. Shorter TTS values indicate that the neuromuscular system can achieve dynamic balance more rapidly following landing, a key indicator of postural control and functional stability (Winter, 2009). Reductions in knee valgus angle reflect improved lower-limb alignment, which is widely associated with a decreased risk of knee ligament injuries, including ACL injuries (Abergel et al., 2020).

Furthermore, the reduction in vGRF indicates more controlled landings with improved force distribution, thereby reducing impulsive loads on the ankle and knee joints (Sun, 2020; Sun & Liu, 2024). The more consistent muscle activation patterns observed in stabilizing muscles such as the soleus and peroneus longus further support this interpretation, suggesting more efficient neuromuscular adaptation. Collectively, these findings reinforce the argument that biomechanics-based interventions not only enhance performance but also function as effective injury prevention strategies within dance training contexts.

The qualitative findings indicate that integrating sports biomechanics also encourages a significant pedagogical shift, moving from imitation-based learning toward a more reflective and understanding-oriented approach. Visual feedback and motion data allow dancers to connect bodily sensations with objective movement parameters, making the learning process more conscious and directed. This aligns with biomechanics-informed educational approaches that emphasize understanding movement principles as a foundation for technical mastery (Knudson, 2021).

For coaches, this approach provides a new pedagogical language that is more objective and communicative without abandoning the aesthetic values and traditions of dance. The impact is evident not only in improved performance outcomes but also in dancers' increased confidence and perceived safety during training. Consequently, the integration of biomechanics offers opportunities for the gradual and contextual modernization of Chinese Classical Dance education—not through the replacement of tradition, but through the strengthening of its scientific foundations.

This study contributes empirically by providing measurable biomechanical data on the *Spinning Dragon Jump*, a technique that has received relatively limited scientific attention. Conceptually, the study proposes a model for integrating art and science, demonstrating that biomechanics-based approaches can be adapted to non-Western dance traditions without compromising their cultural identity. This expands the scope of dance biomechanics research, which has historically been dominated by Western contexts, and opens new possibilities for interdisciplinary dialogue between movement science and performing arts studies.

Several limitations should be acknowledged. First, the sample size was relatively small and limited to specific institutional contexts, which requires cautious interpretation when generalizing the findings. Second, the eight-week intervention period may not fully capture long-term biomechanical adaptations. Third, the study focused on a single jumping technique, which may limit the direct applicability of the findings to other dance movements. Future research is therefore recommended to include larger and more diverse samples,

longer intervention periods, and broader applications of biomechanical approaches across multiple classical and contemporary dance techniques.

Conclusion

This study demonstrates that the integration of sports biomechanics into the training of the *Spinning Dragon Jump* in Chinese Classical Dance significantly enhances technical performance while reducing dancers' injury risk. Compared with traditional training methods, the biomechanics-based approach resulted in improvements in jump height, landing stability, and control of the body's center of gravity, accompanied by reductions in vertical ground reaction force, time to stabilization, knee valgus deviation, and pain levels.

Quantitative analysis revealed significant differences among the biomechanics intervention group, the crossover group, and the control group, with the most consistent improvements observed during the landing phase. These findings highlight the importance of neuromuscular stability and mechanical efficiency as key determinants of both technical quality and dancer safety. The qualitative results further reinforce these findings by indicating increased body awareness and a stronger sense of safety among dancers following the implementation of visual biomechanical feedback.

Overall, the findings suggest that the application of sports biomechanics represents an effective and safe training strategy for the development of classical dance techniques. The integration of biomechanical principles and feedback technologies is therefore recommended as part of dance training practices to enhance performance outcomes while supporting the long-term health and sustainability of dancers.

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